FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT

ELECTRIC HEATED WINDOWS

Thermal comfort and energy use aspects

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PREFACE

First of all, I want to say thanks for Professor Taghi Karimipanah and Roland Forsberg for giving me the opportunity of having access to choose a project like this - a new technology that is still not too developed and that is closely related about my skills like an electrical engineer. But I specially want to use these lines to thank my supervisor in the company and also in the university, Peter Hansson, for all the help and time he has dedicated to this project, offering a flexibility to contact with me and give me the opportunity to work for the company Sweco. Furthermore, along this project I have received a lot of other help and information from many people and I am thankful for the assistance they gave to me. Firstly, I would like to thank Matthias Meisterhans for providing me the different data and measurements needed for the project calculations and also helping me when I have some doubts with them. Finally, also thank to Mohammad Ali Joudi, who with his knowledge with the IDA program, helped me doing the different simulations that are a really important part in my project work.

ABSTRACT

The project aim is to investigate the thermal comfort and the energy use aspects of electric heated windows. New technologies are being developed by some companies around the world. These companies develop homogeneous space heating for the building and therefore, avoid using the typical water radiators. This is a new technology that could be interesting for research and developed for the near futures application with a high possibility for expansion in the markets in a few years. The reason for this is clear. The best conditions for thermal comfort is when all the room surfaces and the indoor air have the same temperature of around 20-22°C. For example, when the outdoor temperature is around 1 or 2 ºC, the temperature of the glass decreases to around 17 ºC. The glass facade becomes significantly colder than any other surfaces or the temperature in the room. Therefore, the radiant heat exchange to the cold window is much larger than towards the room, so the operative temperature deteriorates significantly and consequently causes thermal discomfort and is a good reason for the installation of electric heated windows.

The project is based in the new building in the Sandvik Coromant that is going to be built during this summer 2013 in Sandviken(Sweden). Specialglas is a Swedish company that provides the electric heated windows that will be installed in a big surface area of $57m^2$. This building is energetically analyzed and simulated with the IDA, building simulation program. Hand calculations are also made for demonstrating these results obtained. Furthermore, the positive results obtained in the thermal comfort aspects are given in this project; as for instance the improvement in the thermal comfort index near the window, where the "predicted percentage of dissatisfied" (PPD) for the occupant situated one meter far for the window, varies from 16% with conventional windows to be around 12%, only when the electric heated windows are working at the minimum supply power. The energy that is needed to maintain the same level of the working electric heated windows is difficult to obtain. This is because there are a lot of uncontrollable factors. Even though there is estimated that the energy demand will increase with 15% of the total energy demand.

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INTRODUCTION

The electric heated windows are the topic of the master thesis proposed by SWECO company, sustainable engineering and design company. The company is carried out a project for the new installations for Sandvik company, where I take part as researcher and making this report for the master thesis work. In this case, the project is based and directed for the new building from Sandvik coromat company, that is a part of the business area of Sandvik Machining Solutions within the global industrial group of Sandvik .

Short description: The Swedish company, with more than 8000 employees and being represented in more than 130 different countries, is one of the world’s leading suppliers of tools, tooling solutions and know-how to the metalworking industry, with extensive investments in research and development areas. See figure 1. They create unique innovations and set new productivity standards together with their customers, including for instance the world's major automotive, aerospace and energy industries**[1].**

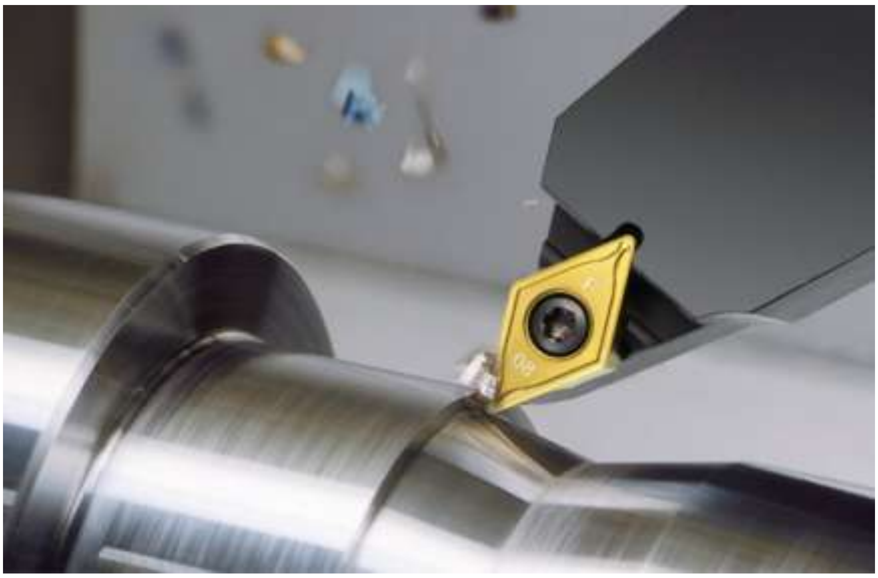


Figure1. metalworking industry [1]

Thereby, his plant situated in Sandviken, that it is shown in the following figure 2, will add a new department building this summer in 2013, where the new technology of the electric heated windows will be used for the offices section in the building. This offices part, consists of two floors with the same structure and dimension in both, and where the electric heated windows takes really importance due to its dimension and the obligation in order to provide a homogeneous comfort in whole the room.

Figure 2. Sandvik Coromant building picture. [1]

The reason is clear, windows are meant to keep the weather out and you comfortable. However, studies show that windows are the largest source of a building's heat loss and drafts - and consequent cause of thermal discomfort, and even more when the window surface area is so big. As the figure 3, graphic shown.

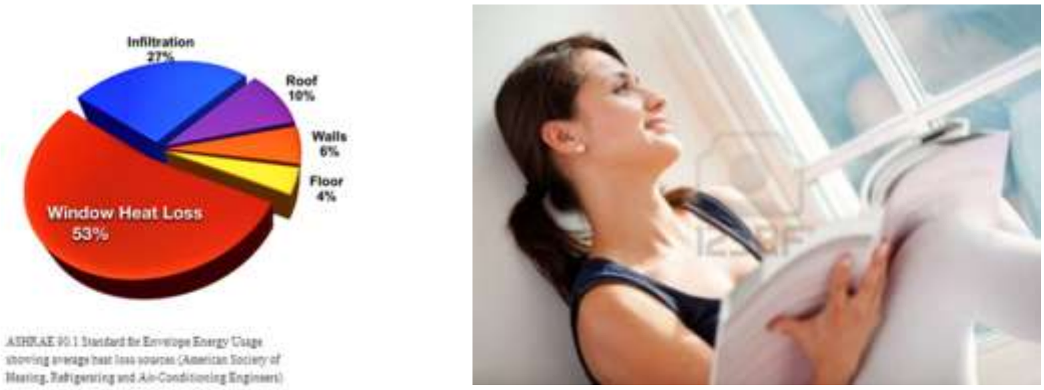


Figure 3. Heat losses by the windows, Power e glass [2]

Thereby, using this technology solves this problem by using a safe electric current, and avoids also using a huge dimension ventilation pipes for heating proposal.

The project aim is to investigate the positive thermal comfort and the negative energy use aspects of electric heated windows. A new technology that is being developed by some companies around the world, which allows a homogeneous space heating in the building and avoid thereby, used the typical water radiators.
The project included the analysis of the thermal comfort in the building and the different possibilities to improve these negative aspects, where the installation of the electric heated windows is chosen finally as the solution of the problems.
First of all, is necessary to study and have the clear concept of the different kind of glasses used for the window and their properties such a U-value, transmittance or the emissivity for instance, and the other parameters of the system too.
After that, the mechanism used to heat the window pane as a radiator is going to be explained, that consist in a few words on the circulation of electrical current thorough an added transparent coating and the final transmission of the heat into the room.
However, the more important part consist of analyze if the system is profitable or not, with the advantages and disadvantages. How much energy it could use compared with another alternative, but also the comfort aspects is important to analyze. The heat losses in the building and the thermal comfort parameters like the mean radiant temperature, the relative humidity (RH) or the activity level for the occupant for instance, are going to use to calculate the "predicted percentage of dissatisfied" (PPD) in the different points of the room. Using IDA computer program to make the different simulations, and given some hand calculations to demonstrate if the results obtained are correct or not.

THEORY

2. 1. THERMAL COMFORT

Brief introduction

In this section, the thermal comfort analysis is divided into three different parts, 2.1.1 human energy balance and general concepts, 2.1.2 how to calculate the thermal comfort and 2.1.3.measurements of thermal parameters and simulation with IDA program that will be explained as an introduction.

As it is known, one of the main objectives of design a new building is to guarantee the thermal comfort of the occupants. The structure and material used in the construction are chosen carefully and lots of studies has carried out for analyze the human comfort perception and behavior. Don´t forget the human spend about 95% of their time indoor.

But, what is actually thermal comfort means and what influenced in it?

As ISO 7730 **[3]** defined, thermal comfort is the condition of mind which expresses satisfaction with the thermal environment. A first requirement for thermal comfort is that a person feels thermally neutral for the body that means he doesn't know whether he would prefer a higher or lower ambient temperature level.

Thermal Comfort is a matter of several physical, but also physiological magnitudes that may be grouped as an environment-related; mean air temperature around the human body, mean radiant temperature in relation to the body, mean air velocity around the human body, water vapor pressure in the ambient air, and person-related; clothing (CLO) and activity (MET) of the occupants, the habits, personal preferences, and actual mood for instance may have an influence in the thermal comfort **[4].** Also, is necessary mention the local thermal discomfort possibilities as air draught, radiation asymmetry, vertical air temperature difference and the temperature on the floor.

How can you calculate the thermal comfort?

Depending of all conditions mentioned before, the thermal comfort can be written as an equation, as it will be explained in the 2.1.2 section, and thus it is possible to calculate the temperature in which the occupant feel in comfort.

However, in a real case with determinate conditions, PMV (predicted mean vote) is used to estimate or calculate which is the degree of discomfort of the people. It could be:

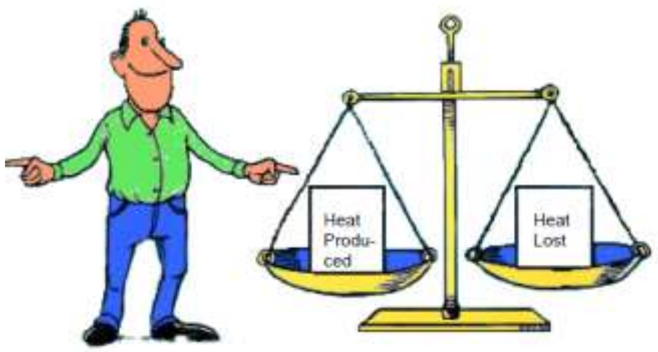
3 hot, 2 warm, 1 slightly warm, 0-neutral, -1 slightly cool, -2 cool, -3 cold

Furthermore, another index used for the analysis of the thermal comfort is the PPD (predicted percentage of dissatisfied) which predict the number, not the level, of dissatisfied people (%) as it is explained later more detailed.

Those indexes can be calculated by hand but also there exists lots of different application software for it, like IDA computer program, for instance.

2.1.1. Human energy balance and general concepts:

It is clear, that human body should be in an **Energy Balance. See figure 3.**



H	(Dry Heat Loss)
E_c	Evaporative heat exchange at the skin
C_{res}	Respiratory convective heat exchange
E_{res}	Respiratory evaporative heat exchange
W	Effective mechanical power, w/m²
M	Metabolic rate, w/m²

Comfort Equation:

$$M - W = H + E_c + C_{res} + E_{res}$$

$$E_c = 3.05\cdot 10^{-3}\cdot\left[5733 - 6.99\cdot(M-W) - P_a\right] + 0.42\cdot(M - W - 58.15)$$

$$C_{res} = 0.0014\cdot M\cdot(34 - t_a)$$

$$E_{res} = 1.72\cdot 10^{-5}\cdot M\cdot(5867 - P_a)$$

H is either measured directly or calculated

Figure 3. Heat produced compared by the heat losses with the respective equations [5]

Where the following parameters and concepts should be understood before doing the human energy balance.

Human body:

The human body is a bad machine what a heat losses referred, with a body core temperature of around 37 ºC, that should be maintained to be in comfort. In other case, there are several heat and cold sensors located in the skin, where they activate and send determinate magnitude impulses to the hypothalamus.

Thus, when the skin temperature is lower than 34ºC or higher than 37ºC, activating the cooling or heating mechanism.

Heating mechanism: Reduced blood flow and shivering.

Cooling mechanism: Increased blood flow and sweating (evaporation).

Human heat losses:

Humans exchange heat with the environment in several ways:

1. Diffusion of water through the skin followed by evaporation
2. Evaporation from airways
3. Convection in airways
4. Evaporation of actively secreted sweat
5. Conduction through clothing
6. Thermal radiation
7. Convection from outer surfaces

[5].

Environmental parametres:

Such an Air temperature, Mean radiant temperature of surrounding surfaces, Relative air velocity and Water vapor pressure in ambient air.

1-Air temperature

The air temperature is the average temperature of the air surrounding the occupant, with respect to location and time. Furthermore, the spatial average takes into account the ankle, waist and head levels, which vary for seated or standing occupants. The temporal average is based on three-minute intervals with at least 18 equally spaced points in time. Air temperature is measured with a dry-bulb thermometer and for this reason it is also known as dry-bulb temperature.

2-Radiant temperature

Unlike the air temperature, the radiant temperature is related to the amount of radiant heat transferred from a surface, and it depends on the emissivity of the material.

Is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure. It could be understand better by the following figure 4.

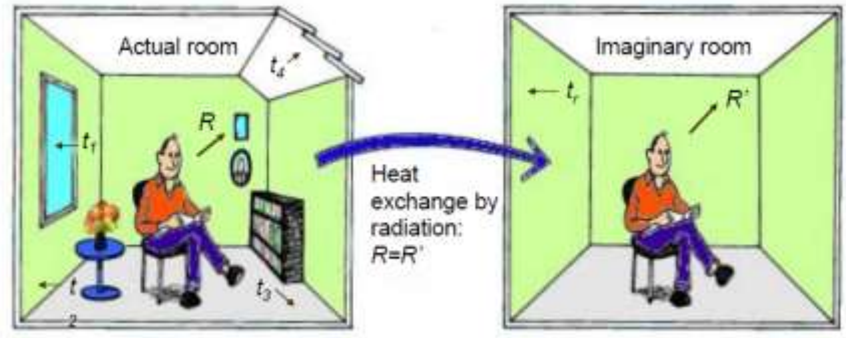


Figure 4. Explanation figure for the radiant temperature [5]

3-Air speed:

Air speed is defined as the rate of air movement at a point, without regard to direction. According to some standard, it is the average speed of the air which the body is exposed, with respect to location and time. The temporal average is the same as the air temperature, while the spatial average is based on the assumption that the body is exposed to a uniform air speed. However, some spaces may not provide uniform air velocity fields and consequent skin heat losses that can't be considered uniform. Therefore, the designer should decide the proper averaging, including air speeds incident on unclothed body parts that have greater cooling effect and potential for local discomfort.

4-Relative humidity

The influence of humidity on the perception of an indoor environment can also play a part in the perceived temperature and their thermal comfort, thus is defined the

relative humidity (RH).

The amount of water vapor in the air at any given time, is usually less than that required to saturate the air, and thus, the relative humidity is the percent of saturation humidity generally calculated in relation to saturated vapor density[6].

$$\textbf{Relative humidity} = \frac{\textit{actual vapor density}}{\textit{saturation vapor density}} \textbf{ X 100 (\%)} \qquad \text{(eq.1)}$$

In other words, the relative humidity is the amount of moisture in the air compared to what the air can "hold" at a given temperature. So if the air is gradually cooled while maintaining the moisture content constant, the relative humidity will rise until it reaches at 100% (this temperature, is called the dew point) and indicate the limit temperature where the moisture starts condensing. See figure 5.

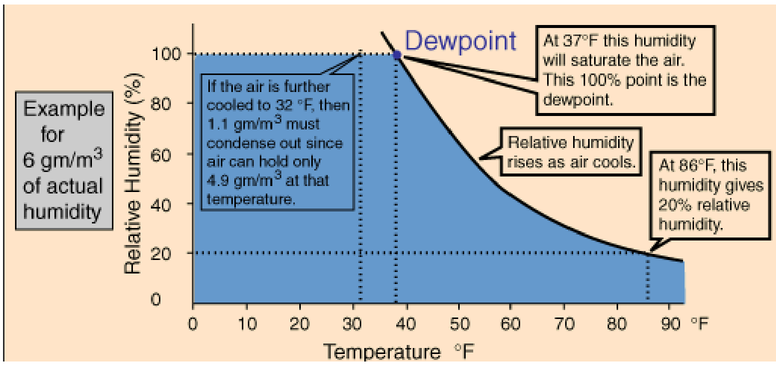


Figure 5. Dewpoint graphics, by Hyperphysics is hosted by the Department of Physics and Astronomy,Georgia State University[6]

The relative humidity affects the evaporation from the skin, which is the higher source of heat losses at high temperatures, normally from 26°C. At lower relative humilities, more sweat is allowed to evaporate from the body, while at higher values it is harder to happen, because the air moisture content is already high. Therefore, very humid environments (RH > 70-80%) are usually uncomfortable because the air is close to the saturation level, thus strongly reducing the possibility of heat loss through evaporation. On the other hand, very dry environments (RH < 20-30%) are also uncomfortable because of their effect on the mucous membranes and it is showed also that it could be the responsible for the sensation of dryness and itching in human. For all of these reasons, the recommended level of indoor humidity is in the range of 30-60%.

Other important factors:

Also the human heat losses mechanisms and the different environmental parameters that affected them, is very important to know what the occupants activity level or metabolism rate is, and what kind of clothes the occupant used. In a few words, is not the same to be studying in a room with a short trousers and a t-shirt, than being doing push-ups or some other sport, when we have a big coat or jacket dressed.

1-Metabolic rate (M):

Metabolism rate of a human is the energy used in the performance of its normal functions including both maintaining the body itself and using the body to perform external functions as the physical work, sports and daily tasks[7].
Measured in met unit, where 1 met refers to the metabolism rate of a sedentary person (seated, quiet), equals to $58W/m^2$.

Metabolism Rate(M) = [Basal Metabolism Rate(*) + Rate of energy use for activity + Rate of heat Energy Produced by body for processing food through the digestive system]

(*)*Basal metabolism rate* (BMR) is the rate of energy expended by the body at rest. This is the minimum amount of energy needed by the organism to perform essential functions such as breathing and associated movements, heartbeat and blood circulation, and the synthesis of molecules e.g. proteins, maintenance of ion gradients across membranes, etc…

The different values of the parameters also depend of each people, his size and age for instance. One way used in the different equations is the body surface area- DuBois area:

$$\mathbf{Ad = 0.202 \,.\, \boldsymbol{Mass}^{0.425} . \boldsymbol{Height}^{0.725}} \qquad \text{(eq.2)}$$

The following table, (figure 6), represents the different metabolism rates values depending of the activity level.

Activity	Metabolic Rates [M]	
Reclining	46 W/m²	0.8 Met
Seated relaxed	58 W/m²	1.0 Met
Clock and watch repairer	65 W/m²	1.1 Met
Standing relaxed	70 W/m²	1.2 Met
Car driving	80 W/m²	1.4 Met
Standing, light activity (shopping)	93 W/m²	1.6 Met
Walking on the level, 2 km/h	110 W/m²	1.9 Met
Standing, medium activity (domestic work)	116 W/m²	2.0 Met
Washing dishes standing	145 W/m²	2.5 Met
Walking on the level, 5 km/h	200 W/m²	3.4 Met
Building industry	275 W/m²	4.7 Met
Sports - running at 15 km/h	550 W/m²	9.5 Met

Figure 6. Metabolism rate values [5]

Where the average activity level for the last hour should be used when evaluating metabolic rate, due to body's heat capacity.

2-Insulation or clothing level (Icl)

Clothing insulation is the thermal insulation provided by clothing, and is one of the most importnat factors that affect the human heat balance. It influenced and makes people feel cold or warm in each moment.

Is measured in Clo unit, where 1 clo= insulation value of 0,155m^2°C/W.

The following tables, (figure 7) shown the clo values of the different type of clothes.

Garment description		I_{clu} Clo	I_{clu} m^2 °C/W
Underwear	Pantyhose	0.02	0.003
	Briefs	0.04	0.006
	Pants long legs	0.10	0.016
Underwear, shirts	Bra	0.01	0.002
	T-shirt	0.09	0.014
	Half-slip, nylon	0.14	0.022
Shirts	Tube top	0.06	0.009
	Short sleeves	0.09	0.029
	Normal, long sleeves	0.25	0.039
Trousers	Shorts	0.06	0.009
	Normal trousers	0.25	0.039
	Overalls	0.28	0.043
Insulated coveralls	Multi-component filling	1.03	0.160
	Fibre-pelt	1.13	0.175
Sweaters	Thin sweater	0.20	0.031
	Normal sweater	0.28	0.043
	Thick sweater	0.35	0.054
Jackets	Vest	0.13	0.020
	Jacket	0.35	0.054
Coats over-trousers	Coat	0.60	0.093
	Parka	0.70	0.109
	Overalls	0.52	0.081
Sundries	Socks	0.02	0.003
	Shoes (thin soled)	0.02	0.003
	Boots	0.10	0.016
	Gloves	0.05	0.008
Skirt, dresses	Light skirt, 15cm above knee	0.10	0.016
	Heavy skirt, knee-length	0.25	0.039
	Winter dress, long sleeves	0.40	0.062
Sleepwear	Shorts	0.10	0.016
	Long pyjamas	0.50	0.078
	Body sleep with feet	0.72	0.112
Chairs	Wooden or metal	0.00	0.000
	Fabric-covered, cushioned	0.10	0.016
	Armchair	0.20	0.032

Figure 7. Different insulation levels [5]

2.1.2. How to calculate the Thermal comfort?

After defined what is thermal comfort and analyzed the different parameters that it should be taking into consideration, is time to study the different indexes and calculations used to determinate the thermal comfort. But, in what ambient temperature does a person experience thermal comfort?

Comfort model:

The comfort equation which is based on the heat balance for the body, can write as:

$$\mathbf{M = Qsk + Qres + S + W} \qquad \text{(eq.3)}$$

M=metabolism

Qsk=heat loss from skin

Qres=heat loss by respiration

S=stored heat, W=work

Rewriting as:

$$M=(C+R+Esk) + (Cres+Eres) + Ssk + Sc + W \qquad \text{(eq.4)}$$

(C+R+Esk)=heat loss from skin by convection, radiation and evaporation

(Cres+Eres)= heat loss from respiration by convection and evaporation

Ssk=heat stored in the skin

Sc=heat stored in the core

W=work

And the heat conduction through the skin as the following equation, and that is shown in the figure 6.

$$\frac{M}{Ad}=\frac{tc-ts}{rs} \qquad \text{(eq.5)}$$

Where:

Ad= 0.202*$Mass^{0.425}$*$Height^{0.725}$[m^2] body surface area.

M metabolism [W]

Tc (ºC) body core temperature (37ºC)

Ts(ºC) skin temperature

Rs the thermal resistance of the skin. Usually varies between 0.05 and 0.08 m^2K/W

See (fig.8).

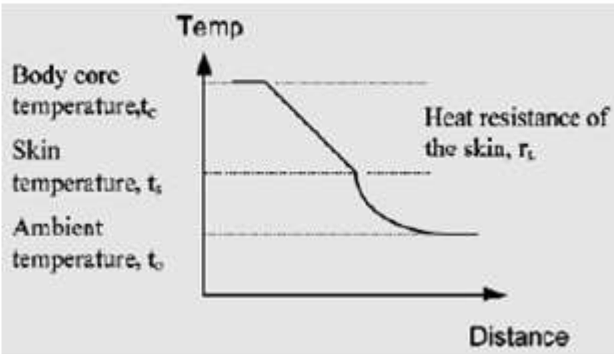


Figure 8. Heat conduction through the skin, represent graphic [5]

Thereby, taking into account both models, the comfortable ambient temperature for a naked person is deduced to:

$$to=tc - \frac{M}{Ad}.(\frac{1}{10}+rs) \qquad \text{(eq.6)}$$

Finally, and considering the clothes insulation, the comfort equation is written as:

$$to=tc - \frac{M}{Ad.fcl}.(\frac{1}{10}+rcl) \qquad \text{(eq.7)}$$

Including:

Fcl= is the clothing area factor (ration between clothes area and total area indoor)

Rcl=heat resistance of the clothes (m^2ºC/W.)

Example:

A person with 1,90m height and 80kg weight is studying in the library. He dressed as the following (figure 9) shows, long trousers, a t-shirt and a jacket and there is around 18 ambient temperature, does he feel in comfort?

Ad= 0.202*$80kg^{0.425}$*$1.90m^{0.725}$ = 2,07m^2

fcl=0.8 (assume)

M=115W

Tcore=37ºC

Rcl=0,141m^2ºC/W.

[1 clo --------0,155m^2ºC/W.

0.91--------x]

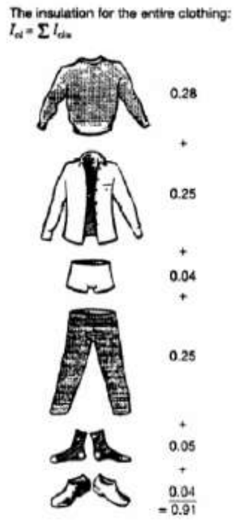


Figure 9. Clothing level of the person [5]

Resolving:

to=tc - $\frac{M}{Ad*fcl}$.($\frac{1}{10}$+rcl) (eq7)

to= 37 - $\frac{115}{2,07*0,8}$.($\frac{1}{10}$+0,141)=20,263ºC

As in the calculations obtained, the comfort temperature for the person is of 20.263ºC, therefore, the person feels a little bit cold with the 18ºC ambient temperature, but anyway is not so far as the neutrality point, to feel in comfort.

Furthermore, it is important to know that for technical and economical reasons a thermal environment which will provide optimal thermal comfort is not always possible. Thus, different kind of indexes like “predicted mean vote” (PMV) and “predicted percentage of dissatisfied” (PPD) are used to provide and analyze the general thermal comfort.

PMV, (Predicted mean vote)

How is measured the cold or warm does a person feel?

PMV (predicted mean vote) is the index used to estimate or calculate which the degree is of discomfort of people is, in other words it predicts the subjective ratings of the environment for a person or a group of people.

That is divided into seven levels as shown in the following (figure 10).

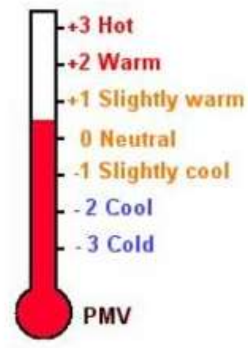


Figure 10. Predicted mean vote, different comfort values [8]

And it can be calculated by the following equations:

Calculations[8]:

$$\mathbf{PMV=(0.303.e^{-0.036.M}+0.028).\ [(M-W) - 3.05.10^{-3}.\{ 5733 - 6.99.(M-W) - Pa \} - 0.42.\ \{ (M-W) - 58.15 \} - 1.7.10^{-5}.\ M.(5867 - Pa) - 0.0014.\ M.(34-ta) - 3.96.10^{-8}.\ fcl.\ \{ (tcl+273)^4 - (tr+273)^4 \} - fcl.\ hc.\ (tcl-ta)]} \quad \textbf{(eq.8)}$$

Where:

$$tcl= 35.7 - 0.028.\ (M-W) - 0.155.\ Icl.\ [3.96.10^{-8}.\ fcl.\ \{ (tcl+273)^4 - (tr+273)^4 \} + fcl.\ hcl.\ (tcl-ta)]$$

$$hc= \begin{cases} 2.38.\ (tcl-ta)^{0.25} & \text{for } 2.38.\ (tcl-ta)^{0.25} > 12.1\sqrt{Var} \\ 12.1\sqrt{Var} & \text{for } 2.38.\ (tcl-ta)^{0.25} < 12.1\sqrt{Var} \end{cases}$$

$$fcl= \begin{cases} 1.00 + 0.2.\ Icl & \text{for } Icl < 0.5\ clo \\ 1.00 + 0.1.\ Icl & \text{for } Icl > 0.5\ clo \end{cases}$$

Where,

PMV = Predicted Mean Vote
M = Metabolism, W/m^2 (1 met = 58,15 W/m^2)
W = External work, met. Equal to zero for most metabolisms
I_{cl} = Thermal resistance of clothing, clo (1 clo = 0,155 m^2 K/W)
f_{cl} = The ratio of the surface area of the clothed body to the surface area of the nude body
t_a = Air temperature, °C
$\bar{t}_r$ = the mean radiant temperature, °C
v_{ar} = Relative air velocity, m/s
p_a = Water vapour pressure, Pa
h_c = Convective heat transfer coefficient, W/m^{2}K
t_{cl} = Surface temperature of clothing, °C

In the other hand, **<u>PPD (Predicted percentage of dissatisfied)</u>** describes the percentage of occupants that are dissatisfied with the given thermal conditions. Where, a PPD of 5% is the lowest percentage of dissatisfied practically achievable since providing an optimal thermal environment for every single person is not possible.

Both indexes are related and can represent graphically as the following (figure 11):

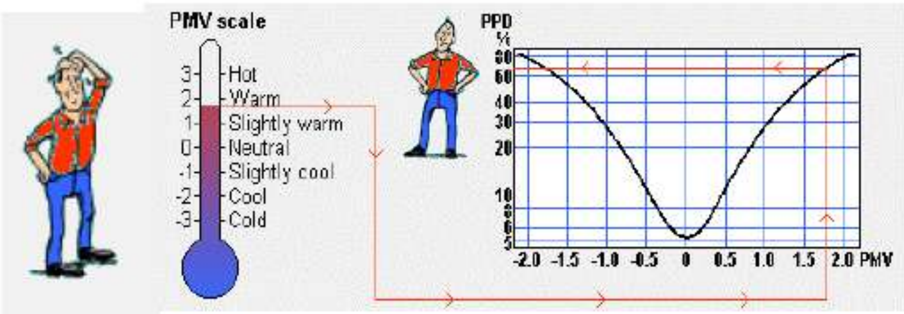


Figure 11. PPD and PMV relation graphic [5]

Graphic based in the equation:

$$\textbf{PPD} = 100\text{-}95.e^{-(0.03353.PMV^4+0.2179.PMV^2)} \qquad \text{(eq.9)}$$

Where there are always some exceptions between people, but in general shows and reflects which the thermal comfort perception for the people is.

As it can be seen in that figure, when a comfort study is made, the percentage of dissatisfied number reflects how people are feeling in that moment. In this case, a PPD of 65% represent a general PMV of around 1.8 near to be warm.

2.1.3. Measurements of thermal parameters and IDA tool:

To calculate the PMV and PPD of the occupants and make a thermal analysis of the buildings, some different computer software is available to use. In this case IDA program will be used, that is one of the easier and manageable one to use and it required first, that all the above-mentioned individual thermal parameters like mean radiant temperature or the relative humidity, must be measured and introduced as the input data for the program. Although in some cases, the same software provided the input data for undefined parameters, for instance in the case of the weather files, a tool makes it possible to define specific weather. In some other cases the data is estimated or approximated too, due to the absence of the real value of the parameters. See (fig.12).

IDA ICE 4.5

Figure 12. IDA ICE 4.5 building program logo [9]

Transducers:

This systems are used for measured the mentioned indoor parameters. A transducer is a device that converts a signal, from one energy form to another energy form, which could be an electrical, mechanical, electromagnetic, chemical, thermal or even acoustical ones. Generally into an electrical signal. See the following (figure 13).

Transducers

- Operative Temperature
- Air Velocity
- Radiant Temperature Asymmetry
- Air Temperature
- Humidity
- Surface Temperature
- WBGT
- Dry Heat Loss

Figure 13. Example of transducer [5]

For example:

1-air temperature measurements[5]:

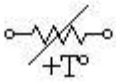
Air temperature Transducer MM0034. See (fig.14)

-Measures actual air temperature

-Shielded against thermal radiation

-Reacts quickly to temperature changes

Figure 14.Transducer MM0034.[5]

Where the value of the resistance of the platinum sensor (Pt100) changes depend of the indoor temperature variation, and as a result having in the measure device more or less voltage drop. 

And as it clearly seen in the following (figure 15).

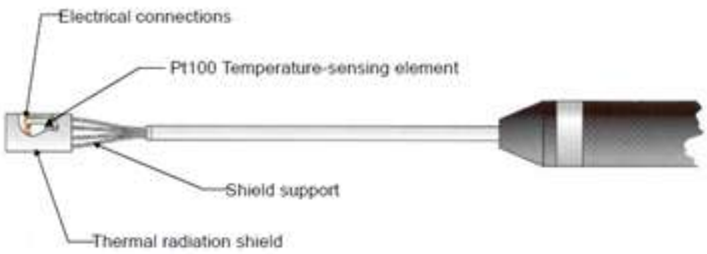


Figure 15. Transducer components [5]

2-humidity measurement:

Humidity transducer MM0037. See(fig.16).

-measures dew point temperature

-provides input for thermal comfort evaluation

Figure 16.Transducer MM0037 [5]

3-air velocity measurement:

Air velocity transducer MM0038 . See (fig17)

-measures air velocity in indoor environment

-provides input for thermal comfort evaluation

Figure 17.Transducer MM0038 [5]

Text about IDA and inputs:

IDA Indoor Climate and Energy (ICE) is a recently developed tool for the simulation of thermal comfort, indoor air quality and energy use in buildings, where the mathematical models are described in terms of equations in a formal language. For the end user, this means that new capabilities will be added more rapidly in response to user requests and that customized models and user interfaces are easily developed[7].

The program is a whole-building simulator, allowing simultaneous performance assessments of all issues fundamental to a successful building design: form, fabric, glazing, heating, “ventilation and air conditioning” (HVAC) systems, controls, light, indoor air quality, comfort, energy use etc. It has more than 900 registered users (mostly in the Scandinavian countries). Specially HVAC designers, but also educators and researchers.

Furthermore, it covers a range of advanced phenomena such as integrated airflow and thermal models, CO_2 modeling, and vertical temperature gradients and it has a multi-level user interface to accommodate different types of users.

See the following (figure 18 and 19) for a typical zone created in IDA program.

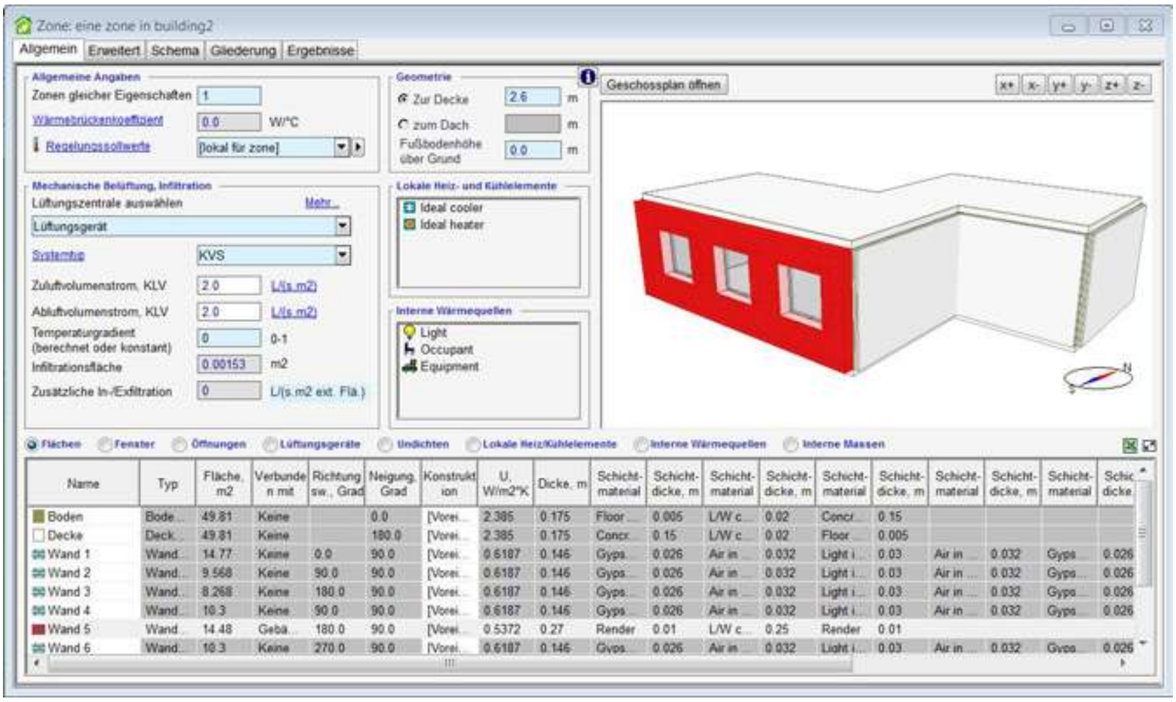


Figure 18. Building simulation example using the IDA program [9]

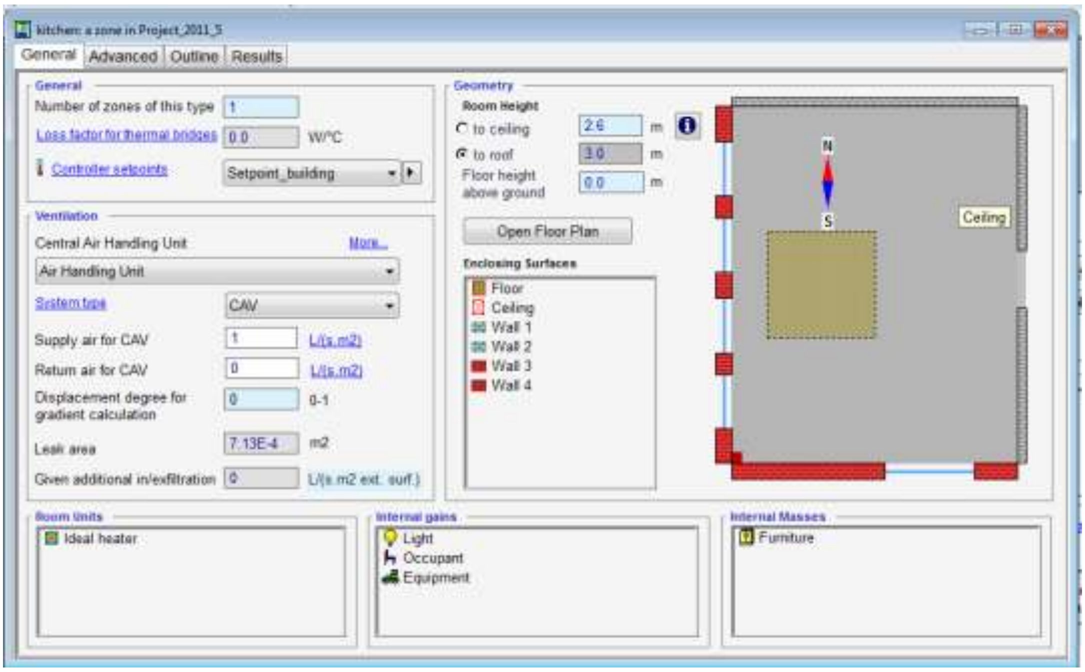


Figure 19 .Other perspective of the building example used in fig.18[9]

Input data required

The main parameters are the climate, the internal loads (from lighting, and equipments), regulators (powers and set-points for temperature, humidity and ventilation), and occupants. Also, is obligatory to know the building geometry and constitution such as air: air volumes, walls (with the materials of layers and the surface parameters), and windows (possibility for solar masks) data too. See (figure 20).

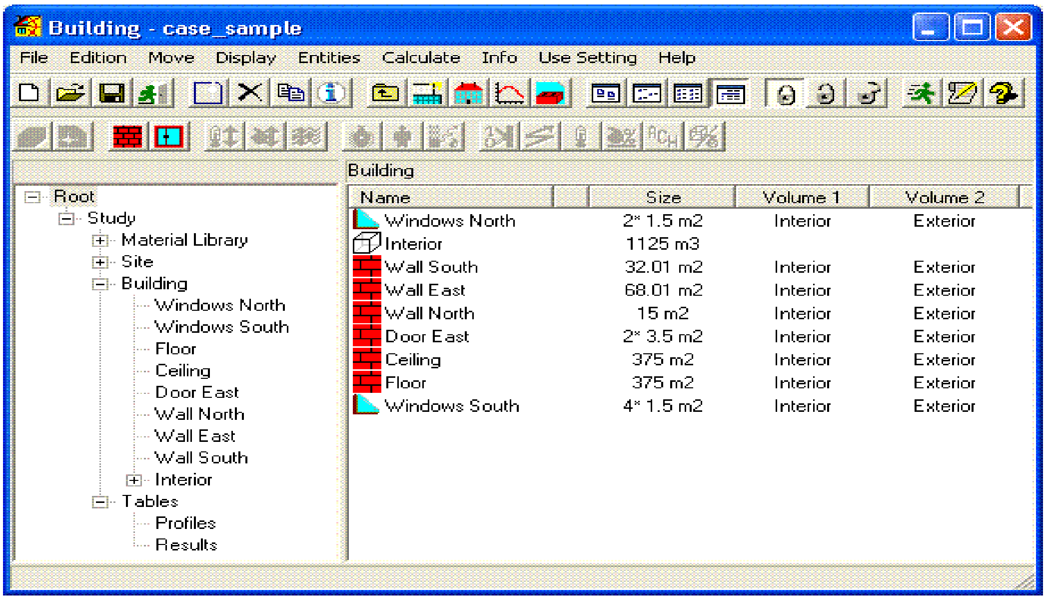


Figure 20. Building structure input data in the IDA simulations[9]

Output data from the simulation tool IDA

Finally, after simulate, run the program the following graphic and tables are taken; showing how is the energy balance in the building is, the thermal comfort for the occupants and so on. It gives the opportunity to analysis in separated, each room of the building and it offer the possibility also to change the different parameters in the system and analysis what improvements could be useful in the case. See the (figure 21).

		Delivered energy	
		kWh	kWh/m²
	Cooling	0	0.0
	HVAC aux	300	2.5
	Electric heating	19403	161.7
	Total, Facility electric	19703	164.2
	Heating	0	0.0
	Domestic hot water	0	0.0
	Total, Facility fuel*	0	0.0
	Total	19703	164.2
	Lighting, tenant	476	4.0
	Equipment, tenant	241	2.0
	Total, Tenant electric	717	6.0
	Grand total	20420	170.2

*heating value

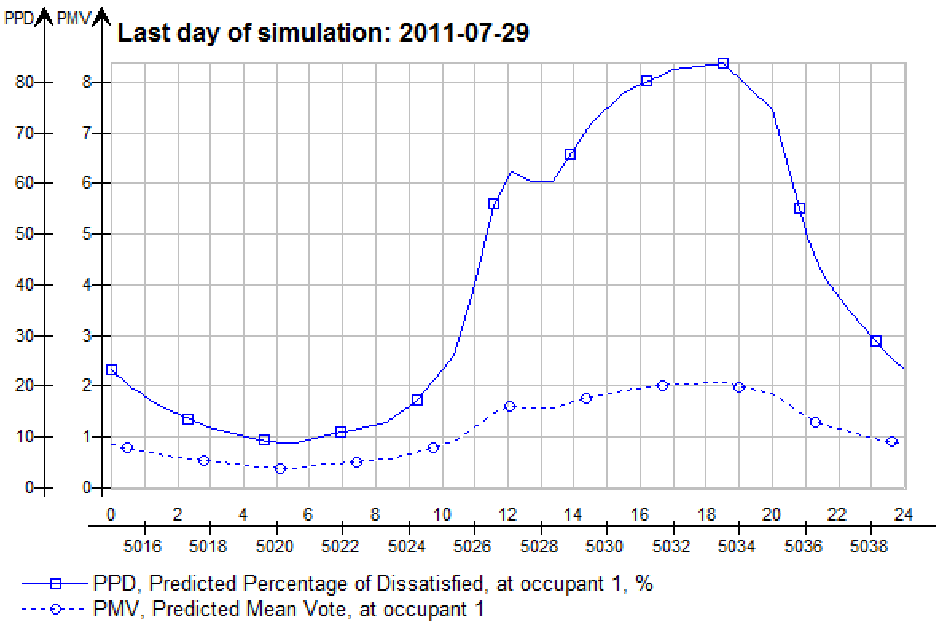


Figure21. IDA simulation results. Delivered energy and thermal comfort indexes referred[9]

2. 2. BUILDING ENERGY SYSTEM

At the time for making a new building or installations, or doing a thermal comfort study for an old house, a climatic design should be planned or defined, where it takes into account all the parameters defined before, as environmental and human factors as well. However the architect or technicians always have some problems for designing a successful model. Problems can occur in the building design factors such as the construction materials, the undefined conditions, the human factor and the climate of the location. Therefore, is necessary to make some estimation of the undefined parameters and other approximations about the data given.

Building factors:

- Although in developed countries architects could have access to building materials characteristics, in many cases there is not exact data about materials.
- Some properties is taken from some standard and reference books.

Human factors:

- In many cases architects could not exactly find a real definition of building occupants during design, maybe in a small building could live five people instead of two people.
- In the other hand, is assumed the different clothing, activities, behaviors, cultures and other human factors, following some studies and standards.

Climatic factors:

- Also the indoor climate, the outdoor climate should be taken into consideration, parameter that is not controllable for the designer and sometimes results difficult get the correct results. For example, it can refer to the nearest climate station. There are possibilities that the information from this station is fluctuating with the near surroundings of the building. There can be different microclimates or the climate can have some difference due to the urban climate factors. These factors can be urban density, streets, parks etc.
- Metrological stations data: Usually, daily or hourly data is not used because of very much time they need to be processed, so the information used is average monthly data.
- Usually is approximated the comfort data as the winter and summer seasons.

Besides all this, don’t forget the architect usually is focused on the esthetical and economical issues, more than finding the optimal comfort conditions for the occupants.

2.2.1. Building energy balance:

The heat balance of a building includes all sources and sinks of energy inside a building, as well as all energy flows through its envelope. This envelope encloses the volume which is kept above a set temperature (in general 20 or 21 ºC) for all weather conditions by the use of heating energy**[10].** The extend of all heat flows, which do hereby occur, is either dependent on external or internal influence factors (weather, user) and these heat flows can be arranged into five categories: 1-Transmission losses, 2- Ventilation losses, 3- Solar gains, 4-internal gains, 5-heating demand. See the (figure 22 and 23).

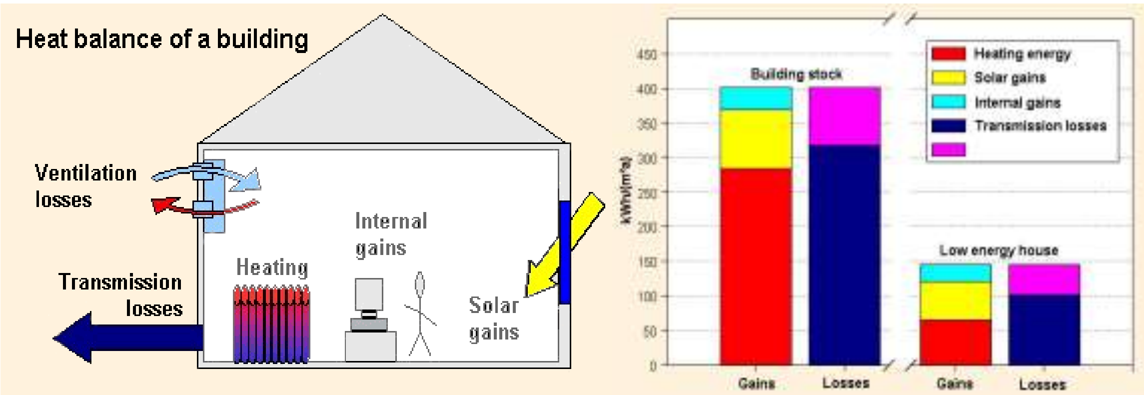


Figure 22.the 5 elements of the heat balance of a building [10])

Figure 23. two examples of a heat balance (for Germany). On the left, a typical balance for the average building stock. On the right, the balance of a low energy building. By Thermal permormance of buildings, German version[10]

According to the energy balance, it is very important to calculate all heat and ventilation losses in the building, and also the internal and sun gains to know finally how much energy is needed to supply in the building.

Transmission losses are those amounts of heat, which flow through the building envelope from inside to outside by conduction or heat transfer, respectively.

$$\mathbf{Qtr=\Sigma(U.A).\ \Delta T\ air = Ktr\ .\ \Delta Tair}\ \ (W) \qquad (eq.10)$$

Where:

Qtr= transmission losses (W)

U= U-value (W/m^2K)

A= area(m^2)

ΔTair= temperature difference between the two zones. (ºC)

Ktr= transmission konductance (W/K)

And Σ(UA)= (U-value*A)walls + (U-value*A)roof + (U-value*A)floor + (U-value*A)windows

Where the lower U-value represent the greater material resistance to heat flow and the better insulating properties. Variable that depends on the thickness (mm) and the thermal conductivity of the material, [λ (W/m K)].

$$\textbf{U-value}= \frac{1}{Rsi+\frac{d}{\lambda}+Rse} \quad \text{(eq.11)}$$

Where:

Rsi= *indoor thermal resistance, with a standard value of 0.13m^2K/W*

d= material thickness (m)

λ= thermal conductivity (W/mK)

Rse= outdoor thermal resistance, with a standard value of 0.04m^2K/W.

However, in the case of the windows is not the simple as in the other materials to calculate the U-value, due to the possibility to find several glass layers with gas or air gaps between. For instance, the use of argon and krypton gas fills, are used with measurable improvement in thermal performance. See (fig.24).

Figure 24.double pane window picture [11]

Argon does not conduct heat as quickly as air, so using argon between glasses, reduces the U-value by approximately 10%, also is a mechanism for reducing the convection way losses, due to argon gas is heavier than air disturbing the natural convection it happens. In general with more glass layers the U-value decrease, but depending of the window coating used, the U-value is going to change too, as we see [APPENDIX A].

Ventilation losses are caused by exchange of warm indoor air with colder outdoor air. The user independent air exchange is through joints by infiltration or exfiltration respectively. In addition, room air can be exchanged through open windows or by a mechanical ventilation system. Ventilation is indispensable, up to a certain extent, to assure the hygienically necessary air exchange rate[5].

$$\mathbf{Qv= (Qv,I + Qv,mech) = \frac{ni.V}{3600}. \rho.Cp.\Delta Tair + \frac{n\,mech.V}{3600}.\rho.\Delta Tair. (1\text{-}\eta t)}$$

$$\mathbf{Qv=Kv.\ \Delta T\ air} \qquad \text{(eq.12)}$$

Where

U = U-value (W/m^{2}K)
ΔT_{air}= air temperature difference (K)
K_{tr} = Conductance due to transmission (W/K)
K_v = Conductance due to ventilation (W/K)
$Q_{v,i}$ = ventilation losses due to infiltration (W)
$Q_{v,mech}$ = ventilation losses due to mechanical ventilation (W)
n = air exchange rate (1/h)
V =volume (m^3)
η_T= temperature efficiency
ρ= density (kg/m^3)
c_p = specific heat capacity (J/KgK)

Total transmission and ventilation losses:

The equation to calculate the total transmission and ventilation losses during the whole year the equation to follow is:

$$\mathbf{E= (Ktr+ Kvent).\ q\ degree.hour\ \ (Wh)} \qquad \text{(eq.13)}$$

Where q-degree hour should be calculated, depending on the outdoor mean temperature where the building is located (T mean) and the balance temperature (Tbalance). The balance temperature is the temperature determinate in each case, taking into account the internal heat generation of the occupants and other indoor sources to arrive for the indoor room temperature chosen.

Balance temperature:

$$\mathbf{Tb=Tr - \frac{Qint}{Ktr+Kvent}} \qquad \text{(eq.14)}$$

Where
E_{tr} = Need of energy due to transmission (Wh)
E_v = Need of energy due to ventilation (Wh)
q_{degree} = degree-hours (°Ch)
T_b = balance temperature (°C)
T_r = room temperature (°C)
$\overline{Q}_{int}$ = mean internal heat generation (W)

Thereby, q degree hour is calculated, as in the following (figure 25).

T_b ºC	T_{mean} °C -2	-1	0	1	2	3	4	5	6	7	8
25	238900	229400	220300	211200	202000	192900	184000	174900	165600	156800	147300
24	230100	220600	211600	202500	192300	184200	175300	166300	[illegible]	148300	138700
23	221400	211900	202900	193800	184600	175600	166700	157700	[illegible]	139800	130300
22	212750	203200	194300	185200	176000	167000	158200	149200	[illegible]	131300	121900
21	204100	194600	185700	176600	167500	158600	149700	140800	[illegible]	123000	113600
20	195500	186100	177200	168100	159000	150100	141300	132400	[illegible]	114800	105500
19	187000	177600	168700	159700	150600	141800	133000	124200	[illegible]	106700	97600
18	178500	169200	160300	151300	142300	133600	124900	116100	[illegible]	98900	90000
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99500	91400	82700
16	161700	152500	143800	135000	126100	117500	109000	100500	92000	84200	75700
15	153500	144300	135700	127000	118200	109700	101400	93200	84900	77200	69000
14	145400	136300	127700	119200	110500	102300	94100	86100	78000	70600	62700
13	137400	128400	120000	111500	103100	95000	87100	79300	71500	64300	56600
12	129600	120800	112400	104200	96000	88000	80300	72700	65200	58200	50900
11	121900	113300	105100	97000	89000	81400	73900	66500	59300	52500	45400

Figure25. degree hour table for the case of the building situated in Sandviken[5]

As it seen in the table , in the case of a steel drawing mill company situated in Linkoping, with Tmean of 6ºC and Tbalance=17ºC, the q dregree hour is=99500ºCh.

Solar gains are irradiations of solar energy through windows and other transparent or translucent constructional elements. Also added to the solar gains, is that part of the solar heating of the opaque building envelope, from which the indoor area benefits.

In the case of the windows as having more layers decreased the heat losses, it decreases also the solar gains to the building. In the other hand, use Low-E coating allows short wave radiation, from the high temperature sun, pass in through the glass, but restricts the amount of long wave radiation, from the lower temperature room, passing out through the glass **[12].** (See figure 26).

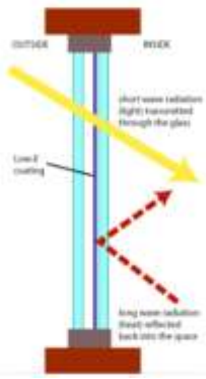


Figure 26. Solar radiation through the window ***[13]***

If the heat flow through a window is calculated, also the heat losses from inside to outside, the sun gain should be calculated as well. For this, the solar radiation intensity perpendicular to the surface (W/m^2) and the transmittance of the window is required in addition of the indoor and outdoor temperatures, and the area and U-value of this one.

Q= [U.A –(Transmitance. A. Intens. Sun)] (eq.15)

Internal gains are heat outputs from persons, appliances, computers and other electric devices, as well as from illumination. Also called as "Internal Heat Generation" (IHG).

The sources of internal heat gains (IHG) include:

1. PEOPLE (sensible and latent heat gain)
2. LIGHTS (sensible heat gain only)
3. EQUIPMENT

a). Receptacles or electrical plug loads (sensible heat gain only)

b). Processes such as cooking (sensible and latent heat gain)

Where part of sensible heat generated by internal sources is first absorbed by the surroundings and then gradually released into the air increasing its temperature. The air temperature is sensed by the control system (thermostat) which operates the cooling system and equipment. So there is a time delay in the corrective action also. IHG can be a major component of the total building cooling load. This is particularly true of nonresidential (commercial, institutional and industrial) buildings**[14].** IHG for lights can be calculated if the type and number of lighting fixtures are known. This is also true for electrical equipment; however, for people and process loads are approximate since the level of activity varies. (IHG) loads for each hour of the year is estimated on the basis of percent of peak design load, like the hourly weather data that affects energy loads due to the building envelope, infiltration and ventilation, internal loads can vary from hour to hour and year to year.

Heated demand

Finally the heated demand is exactly that amount of energy, which is necessary to maintain the desired room temperature by compensating the excess of losses, compared to the gains mentioned before.

2.2.2. Moisture in the building:

It is known that the most buildings are exposed to numerous sources of moisture, whether in vapor, liquid or solid form, for instance due to the content of moisture in many building constructions materials or the occupants delivered humidity. Thereby, as much as water is essential for all forms of life, it brings about deterioration and disintegration of natural and man-made materials, and in this case the interaction of moisture with building materials and components of the envelope may significantly influence the thermal performance of buildings. Also the influence in the thermal comfort for the occupants too and the reason why it will be explained in the next pages. See (fig 27).

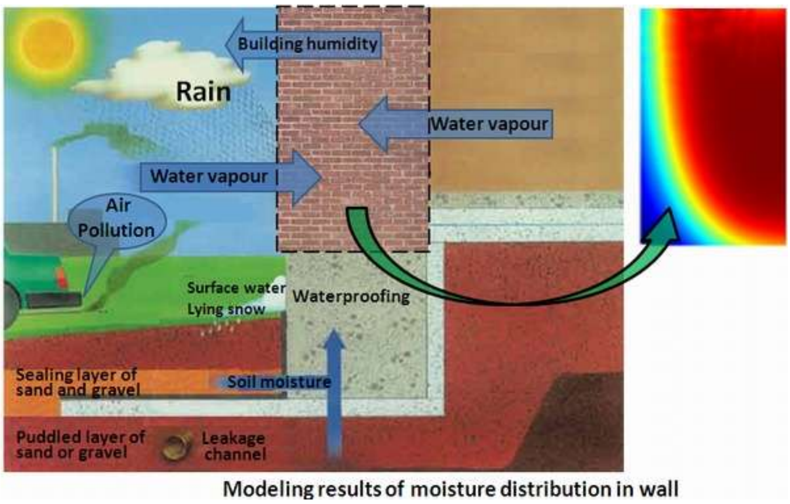


Figure 27.Moisture distribution in a building [15]

<u>Moisture sources in a building</u>

First of all let’s analyze in detail, what is the sources for moisture in a building:

a.Indoor and outdoor air humidity:

Indoor moisture is generated by day-to-day activities such as breathing, cooking, bathing, and washing and drying clothes. Also, this moisture usually is stored during the summer period and is released from furniture and building materials during the winter period.

b.Construction damp (Building moisture)

Many construction materials have a higher content of moisture in their initial state than what is found later in the normal operation of the buildings. Concrete and wood are examples of such materials, where the excess amount of water will be released during the first months or years during which the building is in operation.

c.Precipitation:

The precipitation occurs in different forms such as rain, snow and hail. In combination with the wind, the direction of for instance rain can be anything from vertical to horizontal. The amount of rain hitting a vertical surface is referred to as driving rain.

d.Water leakage:

Water leakages, coming for instance from bursting pipes, can result in severe moisture problems, although in general are not dealt with here.

e.Moisture in the ground:

Moisture can be found in the ground, in the soil materials, in both liquid and vapor phase, generally produced by the ground water or precipitation sources. See (fig.28).

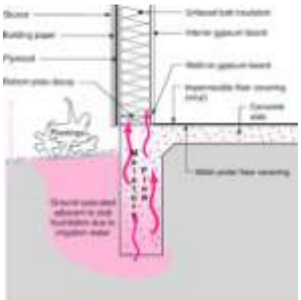


Figure 28. Moisture infiltration process **[16]**

Problems of having humidityes:

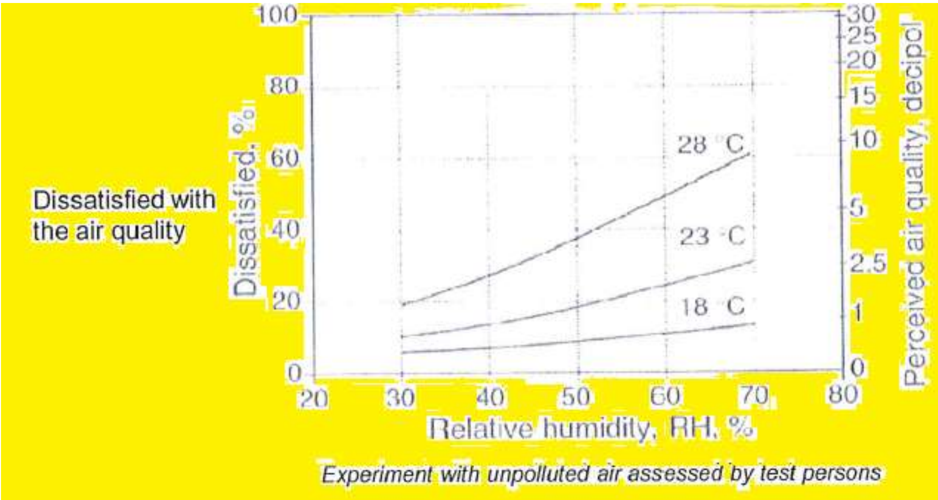
Moisture in the buildings and the relative humidity in the air is an important factor to take into consideration. It could causes big problems in the building envelope, but also affects the human health, thereby the recommended level of indoor humidity is in the range of 30-60%.

Moisture affects the human health

Is not recommended to have a relative humidty below <30%, but neither to have >50%.
If the RH<30%, the human starts getting probles with dry mucous membranes in airways and eyes and it increases the bacterium concentration in the air as well.

In the other hand, rise the relative humidity could be a problem too. At higher temperature and higher humidity, the air quality is sensed as worst **[17].**

As it can see in the following (figure 29).



(Figure 29. relative humidity and temperature, affects the indoor air quality[17]

As big as the RH is, the emissions from materials increases, and the appearance of house dust mites, [propagate at RH>45%] and mould{RH>75%} could happen. The bacterium concentration increases also at high humidity.

2. 3. SPACE HEATING

In this section the different possibilities for space heating are analyzed.

1-District heating possibility:

In northern countries like Sweden, Finland, Russia or Canada with big surface areas where the climate is cold and the energy used for heating is really high; there are lots of forests and trees zones, having the possibility to use the cogeneration plants and the use of district heating network. See the (fig.30).

Figure 30. distribution of the forest in the earth [18]

Cogeneration plants:

These plants generate electricity, but also generate big amounts of thermal energy, that is used for the district heating grid. District heating network connected for the normal houses buildings or factories as well. While in other countries only the electricity is generated and lots of energy amounts are loss by the chimney, here, the fuel energy content is used as much as possible obtaining a high energy efficiency plants.
See (fig.31).

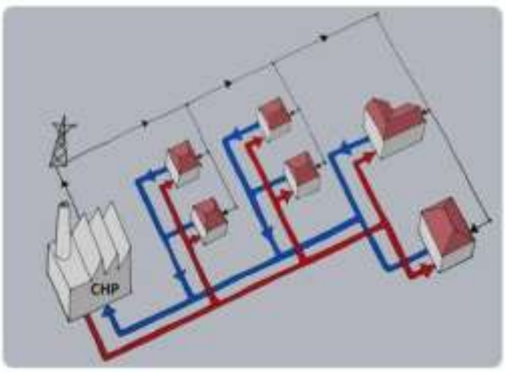


Figure 31. Distric heating system. [19]

Furthermore, it avoids to be depending on the countries with the gasoil and oil pits, like Saudi Arabia, Angelia, Qatar or Iran. And taking into account that some of them are not so stable countries and the fuel source is not infinite, it could be an important advantage. Thereby, in most cases in Sweden cities for instance, district heating system is used to provide the heat needed. The system is simple, the hot water is supplied thorough the pipes toward the houses and then that heat is transferred by a heat exchanger, returning again to the heat plant with a lower temperature of the water. However, and although having the possibility to access for the district heating network, don't forget that it suppose a high investment cost. First of all, they should dig the soil for installing the water pipes; also it requires doing all the paperwork with the companies and so on. See the next (fig.32).

Figure 32. district heating pipes installation [20]

Furthermore, not all the countries have the possibility to use the district heating network, and maybe it is not profitable to install this system depend of the case.

2- Instead, the supply of the **natural gas, oil or butane is needed to heat the water**, with the consequences that it implies. For instance, in regard to the prizes, as it could be seen in the following figure evolution, the tendency of the prizes in the last years shows a really high rise, and nowadays it still follows increasing, as the following (fig.33) shows:

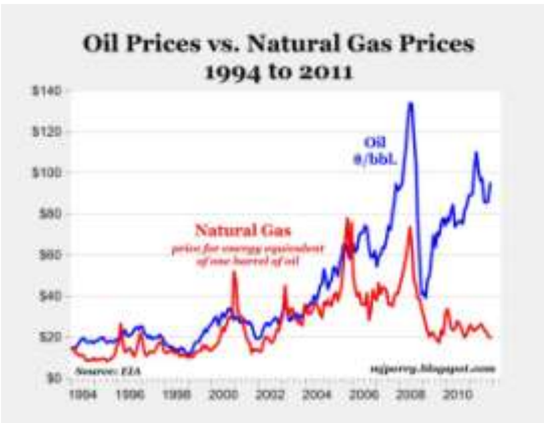


Figure 33.evolution of the oil and diesel markets between 1999 and 2008 [21]

3-Thereby, other kind of systems, as **solar collectors or PV photovoltaic panel** with heat pumps are also used, offering the possibility even to provide the whole demand of the building. For instance the following (fig.34) system.

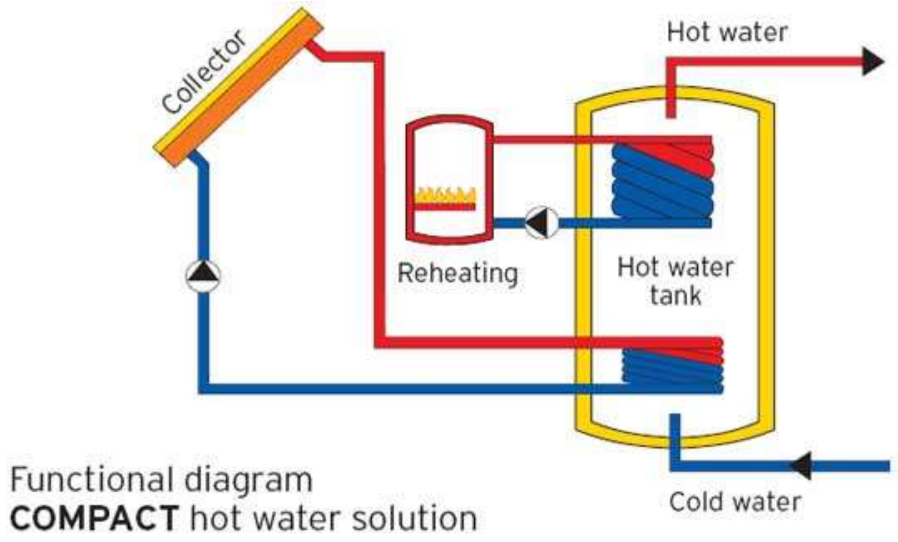


Figure 34. Simple solar collector system schema. **[22]**

4-Electric heaters:

In other case, **electric type of heaters** are also available to use, like conventional electric radiators or in this case of electric heated windows too, offering good heat characteristic but that mostly depending on the electricity prize. For instance, in a country like Sweden where the electricity prize is really cheap comparing with the rest of European countries, making it a possibility to use electricity for space heating and making logical for research of new technologies like the electric heating windows. As shown in the (figure 34) for the case of an indoor swimming pool. Furthermore, it avoid to be depending on more than one supply form of energy and different distribution companies, in addition of esthetic, commodity, efficiency and thermal comfort positive advantages by using this type of technology.

Figure 35. Electric heated windows in a swimming pool **[23]**

Electric radiators:

An electric radiator is simply a device that converts electrical energy into heat, where the heating element inside every electric heater is simply an electrical resistor and works on the principle of **Joule heating**. An electric current through a resistor converts electrical energy into heat energy. For instance, the typical home radiator, as the following (fig.36) , provide a fast flow of hot airy, based on a heat source and a ventilation fan, and as estimation, it generated a heat proportional with the square of the electric current toward the resistences[24].

Figure 36. Electric radiator picture [25]

The energy losses when the electric current is transported, are disipated in form of heat. The resistivity of the material is a disadvantage aspect in the electric energy transport, but is an advantage in this case, when the heat want to be generated. This resistivity, usually increase when the temperature of the material is higher, and its depend on the kind of atoms, the different bonds betwen them, impurityes and so on. (See fig.37)

Material	Resistivity ρ (Ω-m) at 20°C	Temperature coefficient of resistivity (ppm/°C)
Copper	1.68×10^{-8}	3900
Silver	1.59×10^{-8}	3800
Gold	2.44×10^{-8}	3400
Aluminum	2.82×10^{-8}	3900
Lead	2.2×10^{-7}	3900
Tin	1.09×10^{-7}	4500
Tungsten	5.28×10^{-8}	4500
Iron	1.0×10^{-7}	5000
Resistive alloy	1.0×10^{-7}	700

Table. *Material resistivity properties.*

Figure 37. Material electric resistivity and temperature coef. of resistivity values[26]

This heat energy generated by the joule efect, should be transfered for somewhere, in other case, there is the risk of follow increasing the material temperature until finally could melt. So it is why the heaters uses as big area as posible to be in the contact with the surronding ambient, and thus, improve the heat transmissions.

Also, is necessary to have a good control of the temperature, control the thermal equilibrium and use an adecuate conductivity materials, with a good characteristic for the oxidation, and which the resistivity of the material not varies too much with the different temperatures, for instance the Nikel material.

The form of heating:

1-convection

The conventional water or steam radiators, uses the convection fenomenum form for space heating, where the above air on the radiator is heated itself, and the thermal energy is "converted" to kinetic energy, therefore increasing the molecules velocity and expanding around the room. Taking into account also, that as the air tempearture increase, its density will decrease and the opposite when the air temperature decrease. Thus, the air flow rises, transmiting the energy in form of the heat from the surronding objects and touching materials, and then as it cool is falling down to the floor, for start again the convectibe cicle**[27],** and as the following (figure 38) shows.

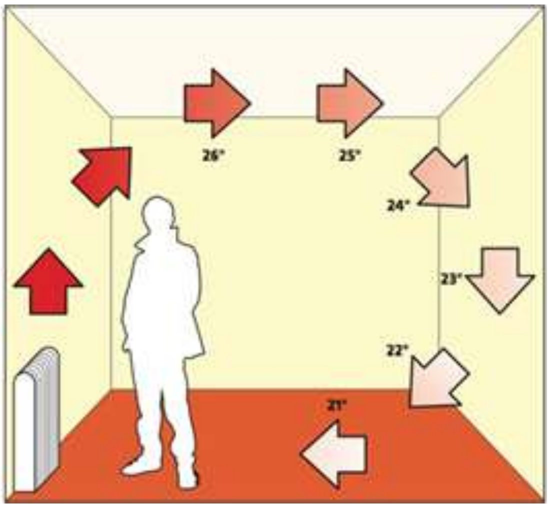


Figure 38. Convection cicle of a conventional radiator[27]

This system, imply the dry air flows could transport the dust and bacterias too, and another disadvantage that following the convective cycle form, the air temperature into the room will be no uniform. The temperature in the greater height, will be higher than near the floor. For instance, in the ankle height where is an important point to take into consideration for the thermal comfort, the temperature will be lower than in the top.

2-Irradiation:

In the other hand, the form of heat with the electric heated radiators is totally different, they used the heat in form of irradiation. The same as the sun, the irradiation heat is multidirectional, and it works as the infrared rays heat the surronding objects and opaque surfaces, without interaction with the atmosphere. See (figure 39).

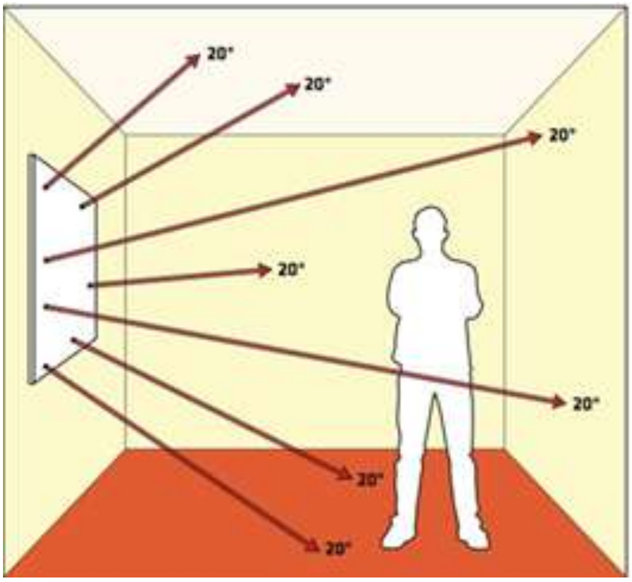


Figure 39. Irradiation picture[27]

Unlike the case expalined before, the conventional water or steam radiators, this system allows to have a homogeneous distribution of the heat, therefore offering a welfare of the human body and avoid to feel the sensation of having a warm head while the legs are cooler. Finally, is important to know that with the irradiaton mode, the heat lead the air in good quality, without the posibuility for transmit or expand dust or bacterias for the room air, thing that is really important for the people that suffer allergies for instance.

2. 4. HEATED GLASS TECHNOLOGY

2.4.1 Glass characteristics:

Glass is an amorphous (non-crystalline) solid material that exhibits a glass transition, are typically brittle and can be optically transparent. Thus, the most familiar type of glass used for centuries in **windows** and drinking vessels, is soda-lime glass. Composed of about 75% silica (SiO_2) plus, sodium oxide (Na_2O), lime (CaO), and several minor additives[28]. As the following (fig.40) shows.

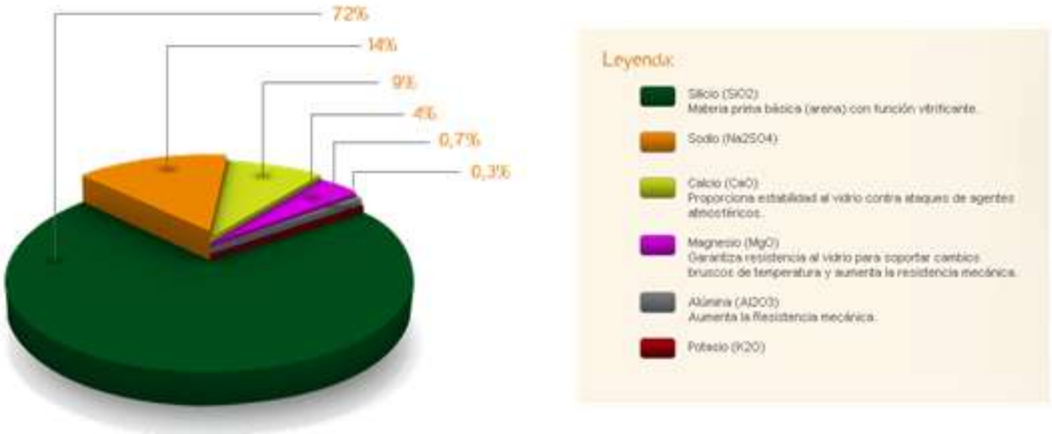


Figure 40. Glass components graphic [28]

Where (SiO_2) is one of the most common constituent of glass, that is formed in nature when the vitrification of quartz occurs. This quartz glass has the following properties:

1- high glass transition temperature of over 1200ºC

2-high resistance to chemical attack

3-density in ambient temperature of 2,2g/cm^3

4-a really small mean linear coefficient of expansion at temperatures higher than 1000ºC, as $5{,}1.10^{-7}K^{-1}$, that allow for instance to warm the glass for a high temperatures and introduce then in a cold water, without fracturing.

5-refractive index for electromagnetic radiation of 1.4589 allowed using for the optical instruments.

6-solar absorptance level, depending on the sun angle of incidence [29].

7-**Electrical resistivity** in the order of $10^{20}\Omega$cm in normal conditions, that means is one of the better electric **insulators** known.

7-Transparent to the visible light and ultraviolet range of radiation too.

The following (figure.41) shows the glass structure and composition.

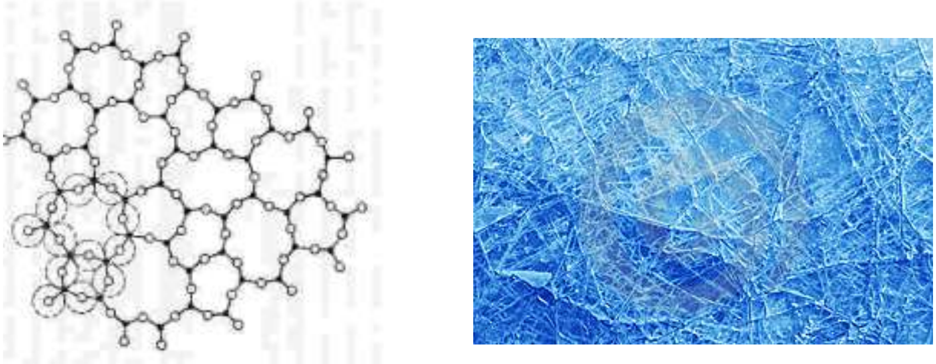


Figure 41. Glass structure.[24]

Furthermore, another substance is also added to the Sio2 as it has been analyzed in the previous graphic, figure 40, like the sodium carbonate (Na_2CO_3, "soda") which lowers the glass transition temperature. However, the soda makes the glass water soluble, which is usually undesirable, so lime (calcium oxide[CaO], generally obtained from limestone), some magnesium oxide (MgO) and aluminium oxide (Al_2O_3) are added to provide for a better chemical durability.

Finally, only to mention, there are more possibilities to change these properties adding extra substances as for instance barium, that lead glass or flint glass is more 'brilliant' because the increased refractive index causes noticeably more specular reflection and increased optical dispersion. Iron which can be incorporated into glass also, to absorb infrared energy, for example in heat absorbing filters for movie projectors, while cerium oxide can be used for absorb also the ultraviolet wavelengths.

Glass-ceramics

Glass-ceramic materials share many properties with both non-crystalline glass and crystalline ceramics. They are formed as a glass, and then partially crystallized by heat treatment and they are used for instance for cooking. It mixes lithium and aluminosilicates that yields an array of materials with interesting thermomechanical properties. Thus, becoming extremely useful for some applications.

In a few words the glass material is electrical insulator, but in other hand, it has good thermal properties that could be useful for this technology.

2.4.2 Coating:

Therefore, it is known that the window pane required a conductive coating, in order to heat the glass surface. Where it will circulate the electricity and the heat losses for the resistance will transfer to the window, increasing the temperature for the whole windows area and this will finally transmitted the heat into the room.

This glass coating is being developed in many years for different companies around the world, as it consists of one of the most important parts of the system. One of the first applications for using electric heated windows was in automobilist systems, mostly installed to avoid condensation in the rear window, but where at first, most notably lines were visible and interfered with vision through the glass. As a solution for the problem, an alternative approach to heated glass is the use of transparent thin-film conductors. See(fig.42). Certain metal oxides can be applied to the surface of glass, resulting in a thin film that conducts electricity and thus, doesn't interfere with vision through the glass. However, another property of these metal oxides is that they reflect the heat, the reason why it should be converted the glass surface from a heat-absorbing (high-emissivity) material to a heat-reflecting (low-emissivity) material**[30].**

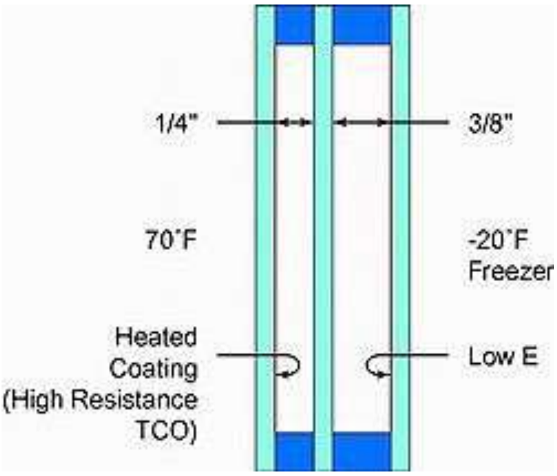


Figure 42. Standard IG Configuration, heated glass. [30]

These coatings are known as Transparent Conductive Oxides (TCOs) and there are actually several different types of TCO materials; the three most common of which are Fluorine-doped Tin Oxide (SnO_2:F), Indium-Tin Oxide (ITO), and thin stacks of oxides and metallic silver. All three of these materials are conductive, heat reflecting, and transparent.

Both Tin oxide based materials and silver-based materials are used in the electronic display industry, but also in the window industry as a low E coating for sealed double-pane window. Also, in general, and economically speaking, the market pricing is roughly similar for both technologies.

However, having the similar properties for low emissivity windows the tin oxide is more tolerant of manufacturing processes and it is the reason why in this case, fluorine-Doped Tin oxide is chosen as the electric heated windows coating, and that is going to be analyzed more detailed in the following.

Properties of Fluorine-Doped Tin Oxide

Tin oxide coatings for Low E window use are available for a reasonable cost, in enormous quantities, on different thicknesses of clear float glass, ranging from 2.3-mm window glass to 6-mm architectural glass.

The Low E glass products have an electrical property described as the sheet resistance, measured in ohms per square (Ω/sq), where the square is dimensionless. This planar property comes from the semiconductor industry and is described as resistivity multiplied by thickness. There is an inverse relationship between the sheet resistance and the heat reflection. The lower the sheet resistance, the higher the percentage of reflection. There are some practical limits to both the sheet resistance and the reflection, due principally to the structure of the coating, as it gets too thick, becomes hazy, and scatters light, and this is undesirable for a window. For Low E windows, the performance attribute requires that the reflectance be as high as possible, which is the same as having the emittance as low as possible.

Glass Type	Sheet Resistance (Ω/sq)	Emissivity	IR Reflectance (%)
Uncoated Glass	Infinite	0.90	10
Pilkington TEC 250	250	0.68	32
Pilkington TEC 70	70	0.44	56
AFG Low E	20	0.22	78
PNA Energy Advantage	11	0.15	85
Pilkington TEC 15	11	0.15	85

Figure 43. Relationship between Sheet Resistance, Emissivity, and the Reflectance [30]

(Figure 43) shows the relationship between sheet resistance, emissivity, and reflectance. The products shown in this table are not all that are available, but they represent the range of values available. Note that the only ones that are used as Low E coatings are the AFG and PNA Products. The other products are produced in lower volumes for specialty applications and are considerably more expensive. Most of the development work done so far has been on products utilizing the Pilkington TEC 15, which is very cost effective and is the most uniform coating available. It is also the most conductive of the common low E products.

2.4.3. Making electrical connection

In order to make an electrical connection with the glass coating, it is common to use busbars: which are a bars of copper, brass or aluminium that conducts electricity within a switchboard, distribution board, substation, battery bank or other electrical apparatus with the main purpose is to conduct electricity. Thereby, the "bus bars" are deposited along two opposed edges of a square or rectangular plate, distributing the current uniformly across the thin film**[27].** See (fig.44).

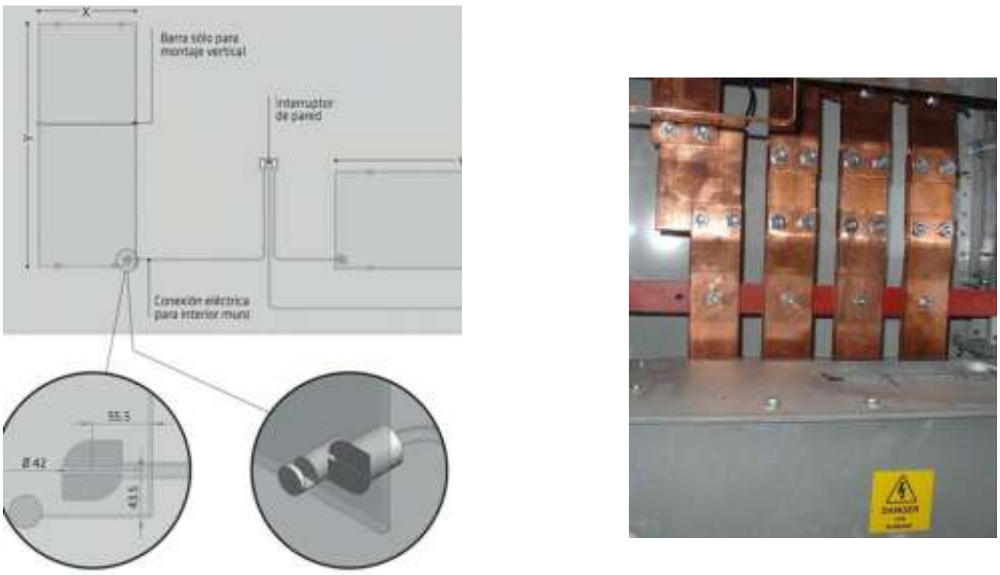


Figure 44. Direct electrical connection to the glass, with special soldering [27]

First of all, <u>the wire or clip is soldered to the bus bar</u> with silver, where the silver frit materials are screen printed onto the glass prior to any heat treating and are fired into the coated surface. Thus, the conductivity is adequate, and they exhibit good adhesion. However, is not as easy as it look like, the soldering operation requires special solder and a special technique to avoid overheating the frit. Furthermore, another disadvantage are the cost of the silver frit (about U.S. $0.25 per lineal ft) and the capital cost and complexity of screen printing **[30].**

An alternative approach has been developed using thermally deposited copper. Patents have been filed on this process, but basically copper is deposited onto coated glass, which is already heat treated in a high-speed proprietary process. The advantages of the copper bus bars include:

- Material cost about 1/10 that of silver frit
- Deposition rates as high as 400 in per min
- Adhesion greater than 25-lb of pull strength
- Conductivity comparable to silver frit
- Low capital cost
- Applied after glass tempering/processing
- Excellent solderability with common electronic solder

This copper bus bar process is available for license for applications including heated glass, switchable glass, and thin film photovoltaic solar cell glass, and it is why nowadays, lots of heated glass products utilize the copper bus bar material. However, it has a temperature limitation, so for an extremely high-temperature application such as coated quartz or ceramic materials, silver bus bars are required, as they can withstand support higher temperatures.

2.4.4. Electricity supply:

On an esthetical point of view, the wires shouldn't be visible in the house in the direct connection with the power outlet, so in some cases, it is possible also to connect with an own switch, on the home electric supply box, that works at 230AC. In the other hand, is important to know also the disadvantages or negative aspects of the coating added for the window. In this case, mention that the electric resistance of the heating surface is fixed; therefore when the different heat output for the system is required, different voltage input would be needed. Thus, the input voltage has to be converted to fit to the wanted power output and the given resistance.

As a consequence energy system needs a calibrated TRANSFORMER and disturbing electrical contacts on two opposite edges of the radiator **[31].** As showed in (fig.45).

Figure 45. Electricity supply for the window, calibrated transformer needed [31]

The picture depicts the transformer as well as the IQ Glass™ control unit. This is a typical size for a medium size conservatory of 25m².

In the other hand, say that **DC** current system is also possible to connect to the glass, thereby a connection from the photovoltaic panels for instance is also possible.

2.4.5. Different applications of heated glass:

Heated glass was first used on a wide scale in World War II to prevent aircraft windshields from frosting over in cold weather and high altitudes and it is still used in aviation for this purpose. In addition, in cars and marine applications, where it is vital to clearly see your way in every weather condition, even light fog or frost**[32].** See (fig.46)

Figure 46. Aircraft with electric heated windows [32]

However, nowadays the most common commercial use of heated glass is to prevent frost from forming on the glass doors of supermarket freezers. In addition, display cases (such as in convenience stores and delis) use heated glass shelves to keep cooked food items from cooling or with the purpose of heating this glass is to ensure that there is no condensation formed on the outer surface, which impedes the ability to see the merchandise in the freezer. See the following (fig.47).

Figure 47. Refrigerator doors. [33]

Heated glass has also been used in architectural window units, conservatories or sunrooms to prevent condensation in the form of frost or fog too. See (fig.48)

Figure48. heated glass application in a modern igloo situated in Lapland [23]

Indoor swimming pools:

A comfortable temperature in an indoor swimming pool produces approximately 70% humidity producing condensation on your glass, unhealthy room conditions, and damage to your structure. With this technology, your glass stays 100% condensation-free, and provides comfortable temperature for swimmers getting in and out of the pool.

And of course for provide space heating in every place where the thermal comfort is required as in homes and offices rooms.

It could find as glass radiators inside the building.

Instead of conventional radiators, these ones are used with an esthetic and indoor design point of view, as for example shown in (fig50 and 51).

Figure 50.Glass radiator in the livingroom[23]   *Fig.51.radiator in the bathroom [23]*

Situated in doors:

Figure 52. Switch on, switch off possibility in the door[23]

And of course, in building conventional **windows**. Offering an efficient space heating system, with an excellent thermal comfort aspects, a few maintenance needed and also insulation for the heat losses between other advantages.

Even more, when the window surface area is high, as in this case in the Sandvic new building would be. With a surface around $57m^2$in the first floor and a second floor around $72m^2$of glass.

2.5 RESEARCH OF ELECTRIC HEATED WINDOWS

The electric heated window is a specific case of heated glass technology mentioned before, and that is going to be analyzed in this project more deep. Trying to find the best product and obtain the best efficiency electric heated window as possible, lots of companies in the world are researching for it. Analyzing and testing the U-value of the window, when it is switch on and switch off too. They apply different pane coatings, different electric supply connection, and try to reduce the production costs as much as they could. Knowing the comfort advantages that the systems offer, they try to make the product a real competitor of the conventional water heated radiators. However, still there are lots things to investigate and improvements to make, mostly energetically speaking due to the heat losses that still suppose the connection of this kind of windows.

2.5.1 What is the real reason to use this technology?

Everybody can check in his house, that the zone near the windows is usually the coldest part of the room, and it is exactly the reason why the radiators are usually situated below the windows. Despite of the research and at the same time the expend of lots of money for improving the U-value of the window, this U-value is always very poor compared to an exterior wall that normally is about 0.2 W/ m^2 ° C. Defined the best conditions for the thermal comfort, where all the room surfaces and the indoor air has the same temperature around 20-22 ° C, it could be demonstrate that even at 1-2 plus degrees outside, the glasses temperature decreases to around 17 ºC and the glass facade quickly becomes significantly cooler than any other surfaces and air temperature. Also, it is checked that radiant heat exchange to the cold window is much larger than towards the room so the operational temperature deteriorates significantly. Thereby, the new technology of the **electric heated windows** avoids these negative aspects heating the glass facade to the room temperature value, regardless outdoor temperature. It eliminates the coldest surface in the room so the radiation heat exchange does not occur on the glass surface. Therefore, the room energy need for heating will be reduced while maintaining the comfort for the occupant at the same time[34].

2.5.2 Window efficiency

Analyzed the windows efficiency is one of the most important parts before installing electric heated windows in a building and the exact calculations for corresponding location should be made, taking into consideration the weather and climate influenced too. However, in this case there are not any tests shown or data offered by Specialglas company for the electric heated windows and thus, in this section, another type of windows will be analyzed as a research. It will be helpful to understand how the windows will work and what variables are the most important to take into consideration. Thereby, repairing for several studies made for the efficiency of heated glass and heated windows, [35], it is shown that the U-value is the most important parameter to analyze.

U-value for the window efficiency:

As it is known, the *U*-value is commonly used to describe conduction losses in building envelope parts, i.e. for wall structures, windows, doors and so on. Thus, in the case in the walls for example, doors or conventional windows, the heat flux through it is constant (in the steady state) in every layer, however in this case of electric heated windows, electrical heating power is switched to the selective layer of the pane. This means that the heat fluxes in the inner and outer panes are not equal and have commonly reverse directions. See (fig53).

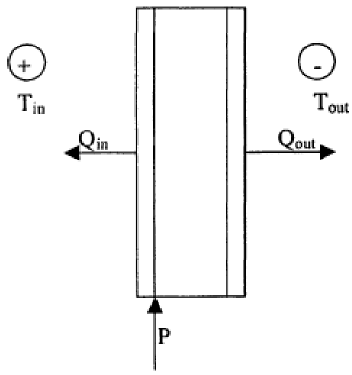


Figure53. Heat fluxes in the heated window. P is electrical heat output to the selective layer and Qin heat flux from the inner surface to indoors (W/m2) [35]

Furthermore, it is demostrated [35] that the heat fluxes in the inner pane are negligible compared with the outer ones, and thereby the U-value of the windows could write as:

$$\text{Uoff}= \frac{Q\ off\ out}{Tin-Tout} \qquad \text{Uon}= \frac{Qon\ out}{Tin-Tout}$$

Therefore, taking into consideration such parameters is possible to say that the **efficiency** of the electric heated windows **is proportional to the outdoor temperature** and practically independent of the inner surface temperature of the window, less than 1%. This evolution depending of the outer surface can be checked in the following graphic, (fig.54), the results of a study done with a common double glazed pane window filled by krypton and an inner surface temperature of 25ºC.

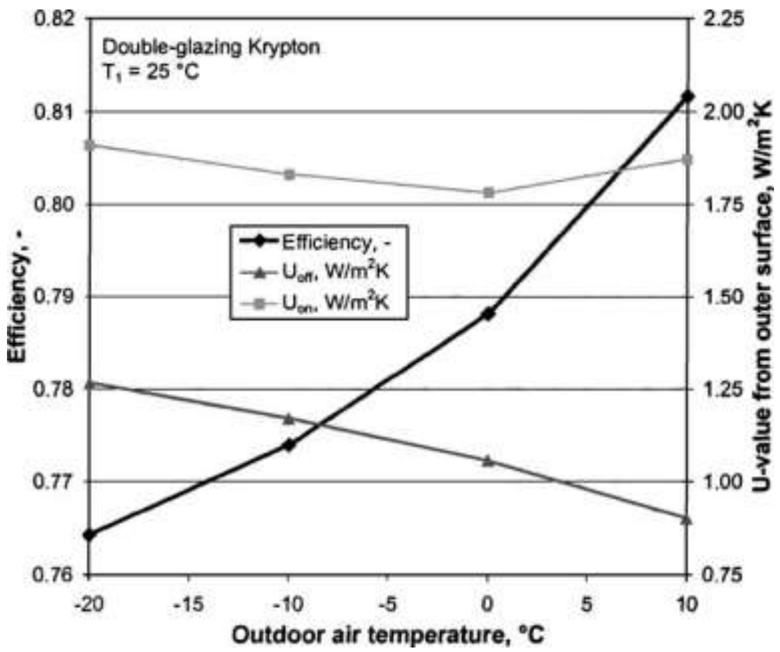


Figure 54. The efficiency and U-values at varying outdoor temperature for double-glazed window filled with krypton [35]

In other point of view, the conclusion is clear, whenever the outdoor temperature is colder, the electric heated window should waste more energy to maintained the 25 ºC of the surface temperature, so the efficiency of the system will be lower. Taking into account the window characteristics for making the shown graphic, and in a town like Sandviken where the mean temperature during the year is around 5ºC, the average efficiency of the window would be around η=0.795.

In the other hand, another testing made plotting graphically all the efficiencies and U-values for +10,0,-10 and -20ºC outdoor temperatures and for 25 and 20ºC inner pane surface temperatures, shows a clear linearity of the results. As showed in (fig.55).

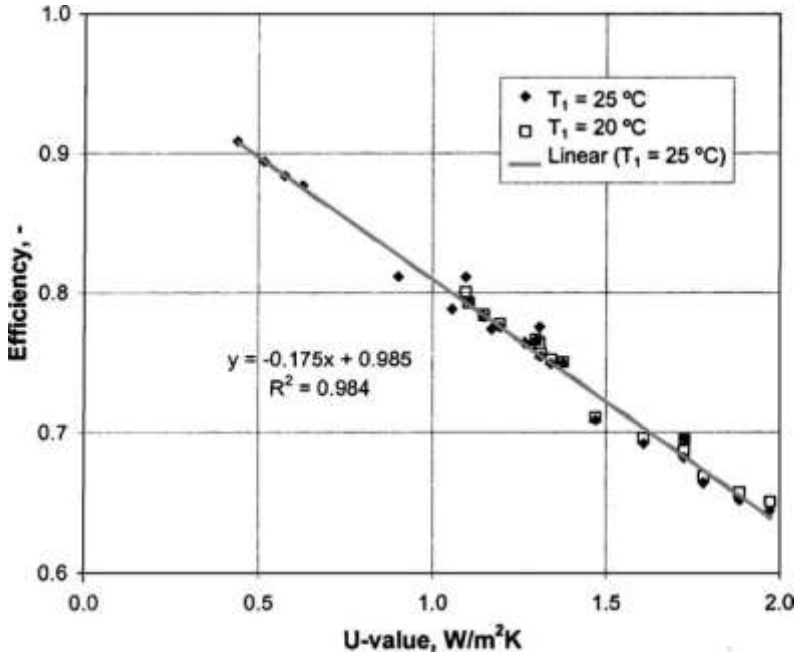


Figure.55. The efficiencies of double and triple-glazed windows filled with air and krypton plotted against U-value of unheated window at +10, 0, −10 and −20 ◦C outdoor temperatures and at 25 and 20 ◦C inner pane surface temperatures [35]

That mathematically can be expressed with very good accuracy as a linear function:

$$\eta = 0.985 - 0.175U$$

And therefore, is clearly demonstrated that the electric heated window efficiency is directly dependent, proportional for the U-value the window acquires each time. Where the U-value at the same time is dependent from the outdoor air temperature.

↓ Outdoor air temperature → ↑U-value → ↓η

2.5.3 IQ type, electric heated windows:

Taking into account the glass properties and the need of adding the coating for the window, in addition of the necessity to insulate the window from the outside conditions, it is clear that more than one layer window is required. Thus, double or triple-pane insulating glass will be used.

In this case, **IQ glass** **<u>double pane window</u>** will be analyzed, a patent kind of electric heated windows provided by the United Kingdom company[31].

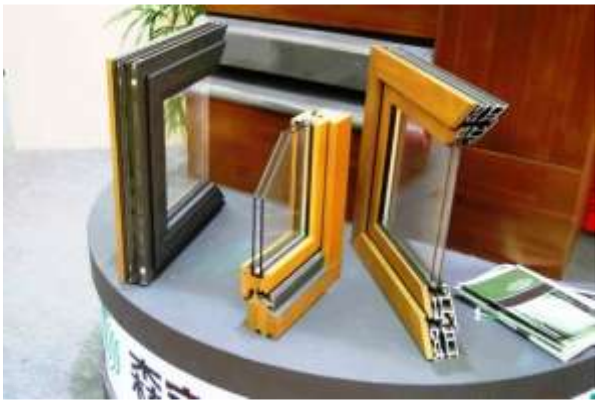


Figure 56. Double pane windows picture [31]

Here, <u>the inner pane</u> of the electric heated window usually has a thin metal invisible oxide coating, that is invisible to the naked eye and has a higher resistance as possible for the transmission of the heat to the inner glass pane. On the other hand, <u>the outer pane</u> has another invisible coating which in this case, has low emissivity and instead of absolved the heat, it reflect the heat losses for transmission from inside to outside. Furthermore, during the hot summer months, this pane repels the blazing heat and ultraviolet rays away from your home. See (fig 57).

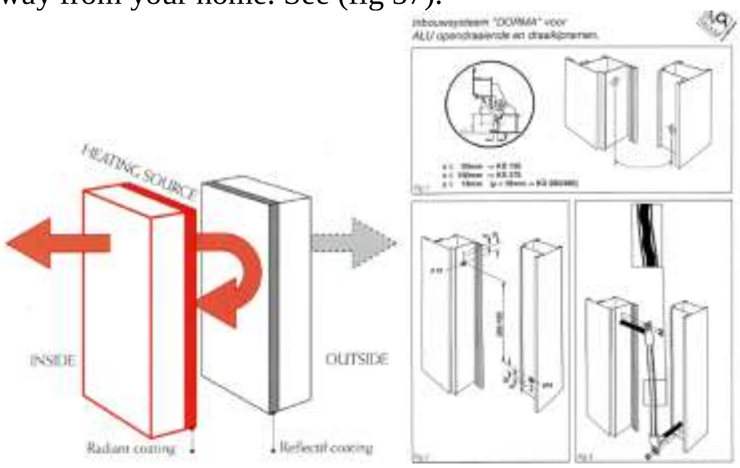


Figure 57. Heat transfer from the window [31]

Following the IQ glass characteristics[31], both pieces of the glass consist of tempered glass that is five times resistant, stronger than normal glass, with the disadvantage that if it broke a part of it, immediately the window will fracture into distinct fragments. In addition, a non-toxic insulating gas called krypton is placed between the panes, achieving an amazing level of thermal insulation, currently unmatched in the industry. This means no more cold drafts slipping in through the window crevices.

Technical parameters values:

- The interior pane is heated up by the Joule effect with a specific maximum output of 250W/m^2 (maximum energy use per square meter)

- The exterior pane can also be tempered, and has a low-emission layer of 0.04 on the inside.

- The gas filling in the cavity is 95%krypton and 5% air.

- The U value in conformity EN ESO 10077 is 0.92W/ K. m^2, when is switch off.

Really good compared with the 3W/K. m^2 of the conventional double pane window, but taking into account the problem of external water condensation occur ***[36].***

- A solar gain of 54% (energy savings)

- The edge sealing consist of a two barrier system sealed against gas and moisture or a special hot melt butyl highly sealed against steam diffusion.

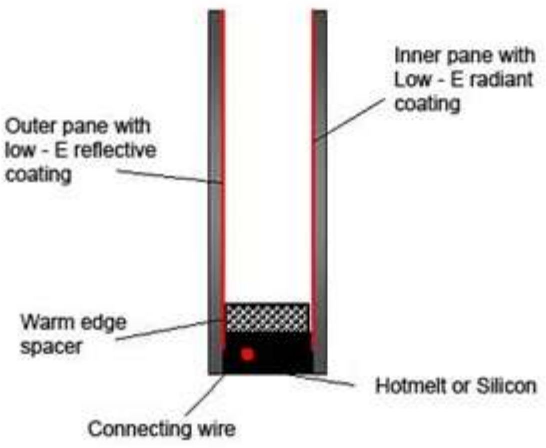


Figure 58.IQ glass structure [31]

2.5.4 Other heated glass companies:

Electric heated windows could be a real possibility for space heating in houses and other kind of buildings in the future application. Therefore, some companies around the world are trying to research or investigate the improvements of this system. As the following figure show some examples for the different companies. See (fig 59).

Figure 59. Different companies investigating the electric heated windows

METHOD

This project is divided into two different sections, as the following schema shows. See (fig.60).

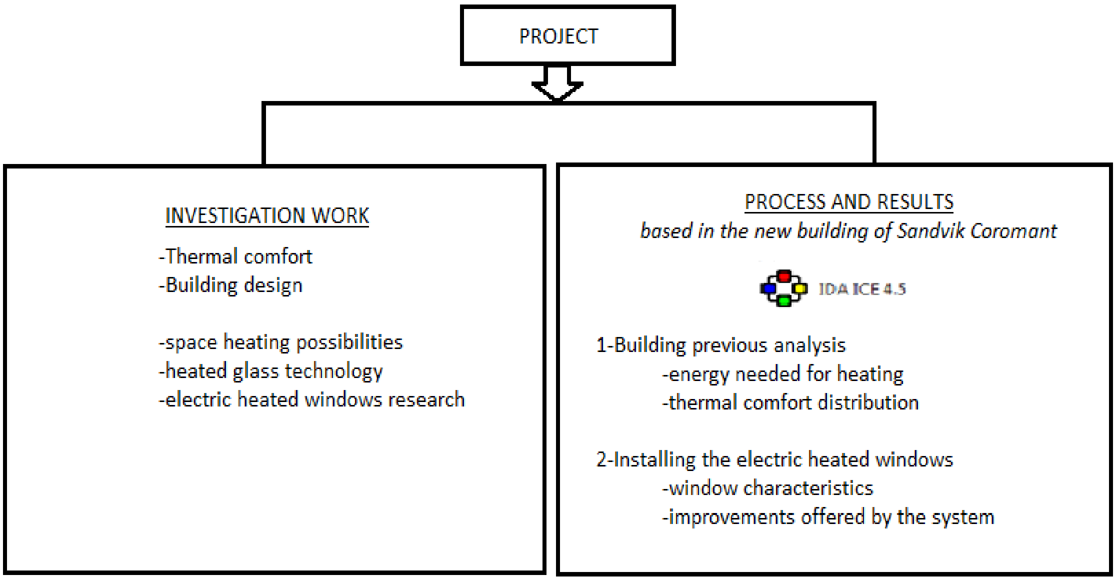


Fig 60. Project distribution schema

Investigation work

The first part, the theory part in this report, consist on the investigation work and research in this new technology, heated glass and especially in electric heated windows. For this part, first of all, normal windows characteristics have been analyzed, different kind of glass, his structure and characteristics. Online encyclopedias have been consulted, university class notes and basics definitions in books and in scientific articles. When the general concepts and knowledge about the windows is taken, is time to research in modern and different new technologies used with the windows. Windows used as photovoltaic pane, windows with an extremely low U-value characteristic and of course the different methods to heat the glass and working as an electric radiator. Heated glass or thermal properties of the glass are used as the key to research in internet, and several web pages have been read in English, but also in Spanish or Italian too. Once, when heated glass companies web pages are found, is time to read and analyze their used technology, their windows properties, the connection method, the control system used and explain it in the report, in a clear way.

Process and results

The method used for making the second part of the project is specially based in the given explanation and the different data offered by Sweco company. Making the different simulation by using the IDA program. The dimensions of the new building is given to me directly, see (fig.58), also the U-value differences into the room, the ventilation rate and the internal heat generation, considering the working hours in the future building. Besides, the information of Specialglas company provided windows and the access of some specific scientific articles is given to me. Using this information as the input data for the IDA program, the building first floor is designed and built in the program. First of all, it is checked that the designed building is correct at all. Analyzing for instance the wintertime or summertime cases and different location changes in the results, but also the building energy balance, the thermal comfort indexes and the temperature distribution in the building are observed.

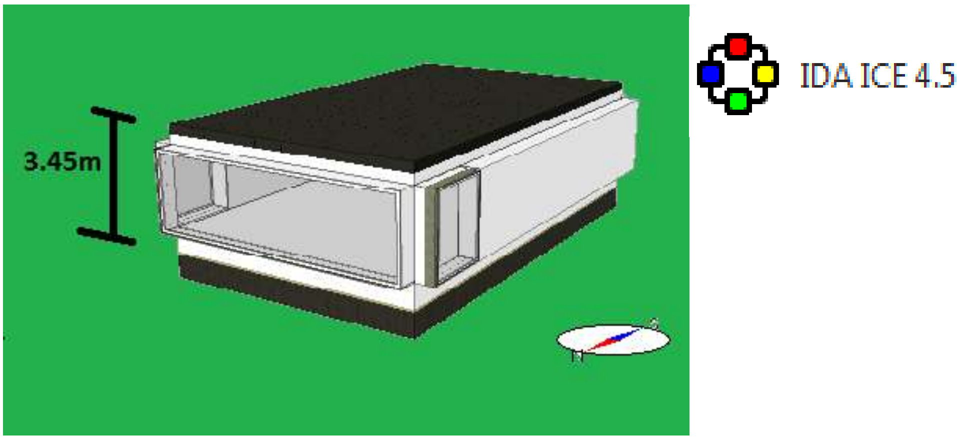


Figure 61. Building dimension II, by IDA program

The building previous analysis is made when the electric heated windows are not installed yet, or when they are in OFF mode. The energy losses in the building and the discomfort problem for the occupants situated in the windows are observed in this case.

Finally, different simulations have been tried in order to copy the effect of the electric heated windows. It consists of the more complex part in the project, because it doesn't exist a direct possibility to introduce an electric heated window in the program. After the different methods used, as it will be explained in the Process and results, "4.7 Thermal improvements" section, the system will finally be simulated correctly. Therefore, the desired thermal comfort improvements in the building are finally obtained as a result. The correspond PPD in each position for the occupant.

PROCESS AND RESULTS

4.1 DIMENSIONS AND GIVEN DATA FOR THE WORKING AREA

The working area, where the electric heated windows are installed is represented by the next AUTOCAD, (fig.62), and it also could see in the whole building planes pictures showed in the [APPENDIX B].

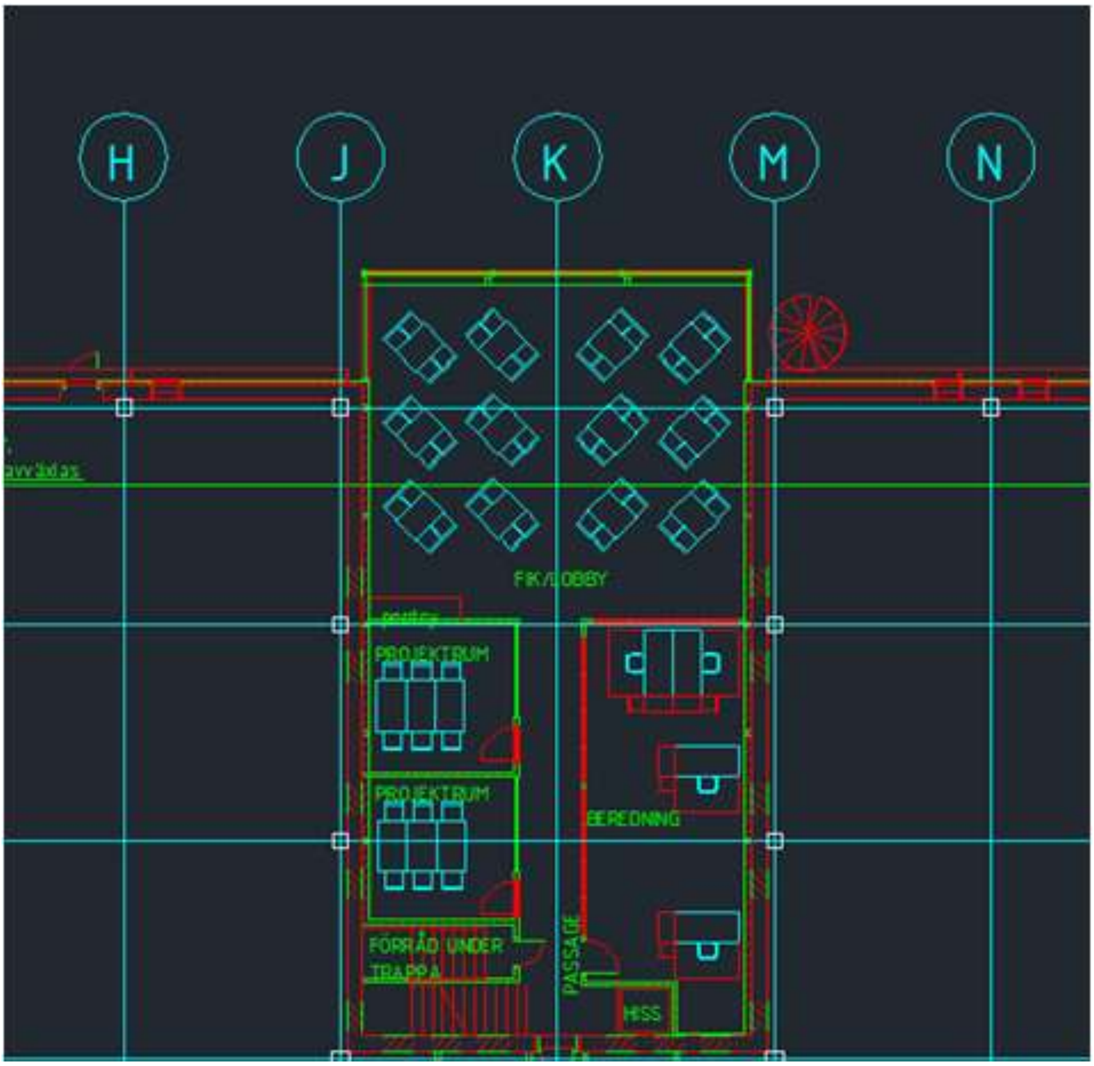


Figure 62. offices part of the new building, by AUTOCAD

Where all the area showed in the picture will be analyzed, simulated and make the respective heat losses calculations, but knowing that the bigger room above the picture that is near the glass, will be more directly influenced by the electric heating windows action and therefore will be analyzed more in deep.

Dimensions: It consists of two floors building, having the same structure in both.

The horizontal dimensions like the following, (fig.63).

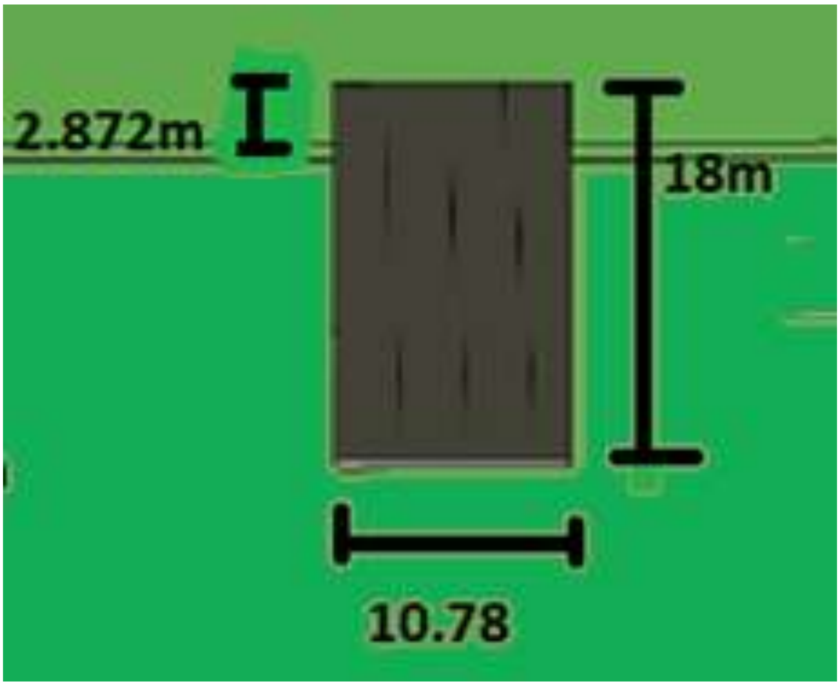


Figure 63. Building dimensions I

-While the heigth of the building is considered as equal in the two foors. (Fig 64).

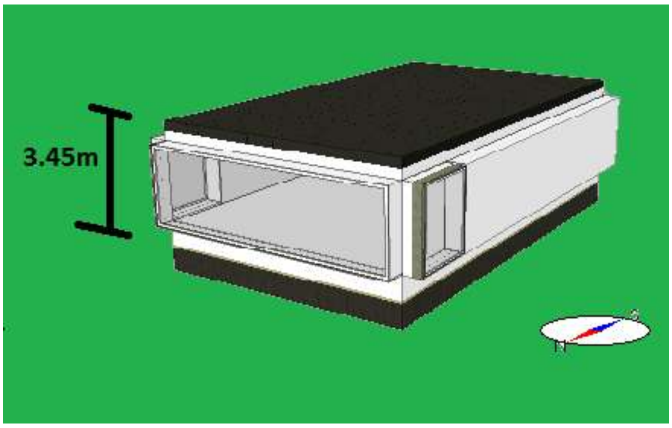


Figure 64. Building dimensions II

-The U-value of each walls, floor, ceiling, doors and everything has been measured carefully by another employees in **Sweco** company. Thereby, the results of the dimension and the U-values of each part are given to me directly, having the possibility to simulate and make the hand calculations with a higher accuracy as possible. [APPENDIX C] shows the different parameters that it is given to me.

However, and as considering in the whole building there are 22ºC provided by the ventilation system, there won't be any heat transfer between the different walls of the building. Thus, it has only to take into consideration the heat losses by the floor, ceiling and all the glazing area that is connected with the outside.

Thereby, the data needed for the calculations are the following ones.

FLOOR:

Where the U-value distribution is not homogeneous as shown in (fig.65). It could be seen that as near as the windows are, the U-value is higher for this case. It is explained as the soil has more content of humidity and water in contact with the outside weather.

Yellow surface, S=14,26m^2→ U-value=0,21479 W/m2 ° C.

White surface, S=58,71m^2→ U-value=0,141729 W/m2 ° C

Pink surface, S=121,07m^2→U-value=0,124135 W/m2 ° C

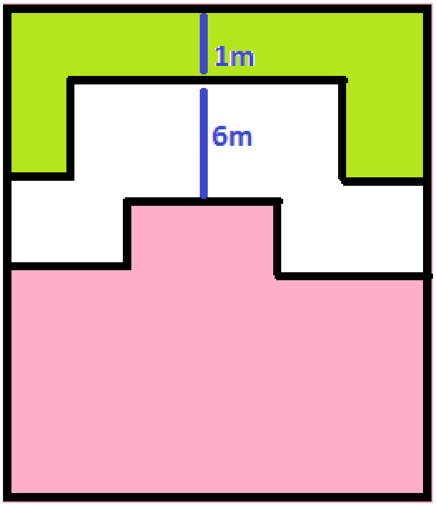


Figure 65. U-value distribution in the floor

For the total surface area of S=194,043m^2:

U-value= $\frac{(14,26*0,21479)+(58,71*0,141729)+(121,07*0,124135)}{(194,043)}$ = 0,1361 W/m2 ° C

ROOF:

S=194,043m^2→ U-value = 0,106 W/m2 ° C

WINDOWS: (6mm-16mm-6mm)

S=57,0078m^2→ Uvalue ≥ 1,5 W/m2 ° C

-Indoor temperature: 22ºC

-Location: Sandviken.

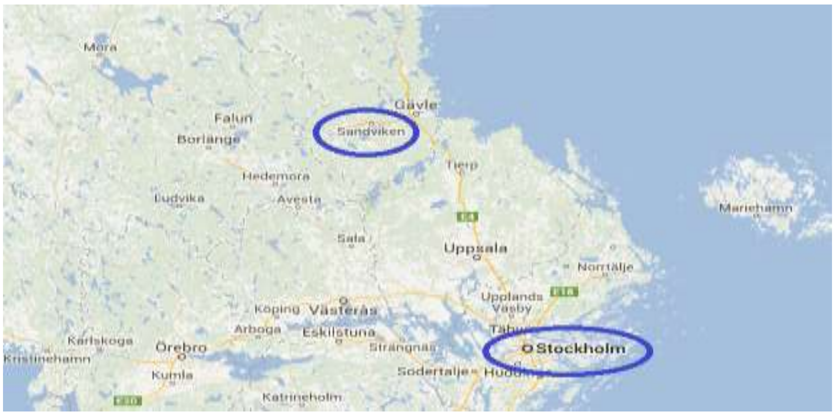


Fig. 66. Location of the building analyzed

-Internal heat generations (IHG)

Monday-Friday: 8:00-16:00

Equipment: 5W/m^2

Persons: 18 W/m^2

Light: 10 W/m^2

-Ventilation system:

Monday-Friday: 7:00 to 16:00	Rest of the time, also weekends
500 l/s	100 l/s

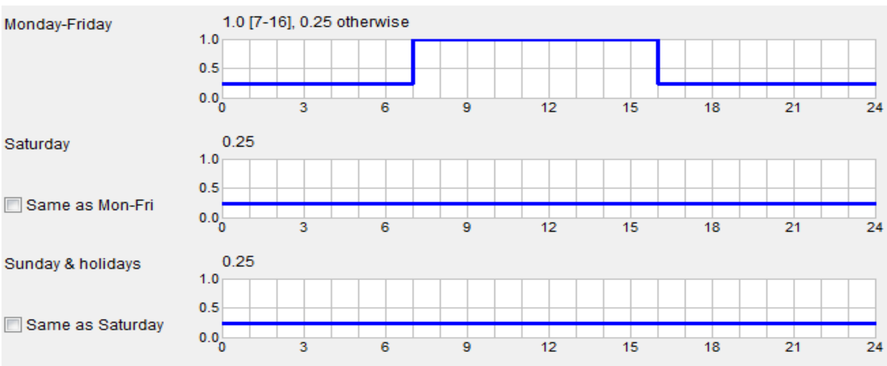


Fig.67. Ventilation system schedule by IDA program

4.2. HEATING ENERGY NEEDED

Calculate the heat and ventilation losses in the working area is very important to know how much energy is needed to compensate this losses, or in other words, how much heating energy should be supply during the year for having a constant comfort temperature of 22ºC.

4.2.1. Energy loss calculation

For calculate the building heat losses, the process explained in the theory will be followed. Therefore, all detailed calculations are shown in the [APPENDIX D] and the following final result is obtained.

Energy = (Kventilation + Ktransmission) * qdegree-hour (eq. 13)

*E= (248,57+111,92)*103081,81= 37,16MWh*

Where, the energy needed for heating the offices room in the first floor and maintaining an average comfort temperature of 22ºC is 37,16MWh/year.

4.2.2. IDA program simulation

IDA ICE 4.5

In order to demostrate the realized calculations, IDA building computer program will be used, with the dimensions and input data showed in [APPENDIX E]. And where, the following results are obtained as (fig.68) shows.

		Delivered energy		Demand
		kWh	kWh/m^2	kW
	Lighting, facility	4073	21.0	1.95
	Electric cooling	2224	11.5	4.71
	HVAC aux	7216	37.2	0.86
	Electric heating	31964	164.8	13.84
	Total, Facility electric	45477	234.4	
	Equipment, tenant	2026	10.4	0.97
	Total, Tenant electric	2026	10.4	
	Grand total	47503	244.9	

Figure 68. Delivered energy overview

The results obtained show the need of 31,96MWh/year for heating the space. This result is reasonable taking into account the IDA program used Stockholm city like the location of the building, where the outdoor main temperature is warmer than in Sandviken case.

4.3. THERMAL COMFORT DIFFERENCES INTO THE ROOM

In the analyzed room, in spite of the all energy used for the heating proposal that is around 37MWh/year and all the money that it suppose, is not enough for satisfying the comfort for all the occupants that is working there. This is the reason for making this project and the final solution of the installation of the electric heated windows. Thus, is clearly demonstrable that the thermal comfort for the occupant is not totally homogeneous, there are differences between one and another point of the room. Furthermore, it could be demonstrated that in a winter day in Sweden, the feeling of cold is clearer as near as the window the occupant is. In fact, one of the main objectives of this project consist of simulated and calculated this differences into the room, and show the significantly improvements that will carry when the electric heated windows are installed.

IDA SIMULATION

In order to demostrate the main causing of the thermal discomfort problem into the room, several different simulations are tried by using the IDA program. Thereby, one of the successful attempts given is based in the heat energy balance of the building. As it could be seen, the following (fig.69) corresponds of the energy balance in whole room.

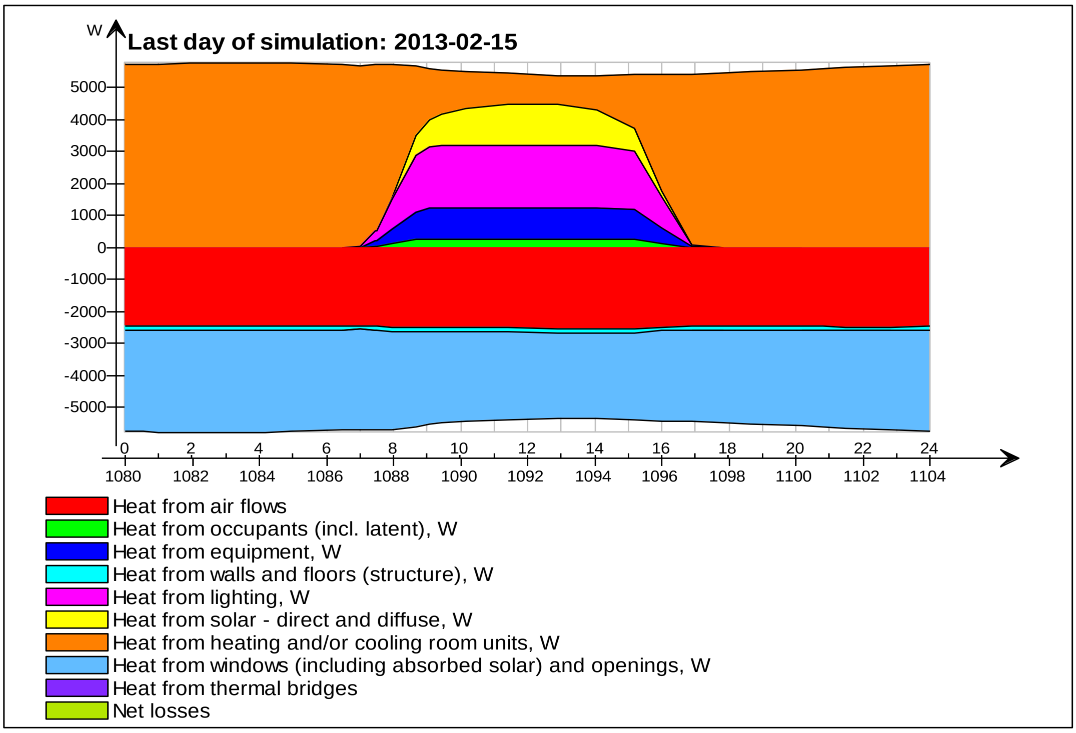


Figure 69. Building energy balance, IDA results

Now, and as the following (figure.70) shown, our building will be divide into two different zones, connected each other with an opening. In this case a door is used between the two different zones, yellow colored in the figure.

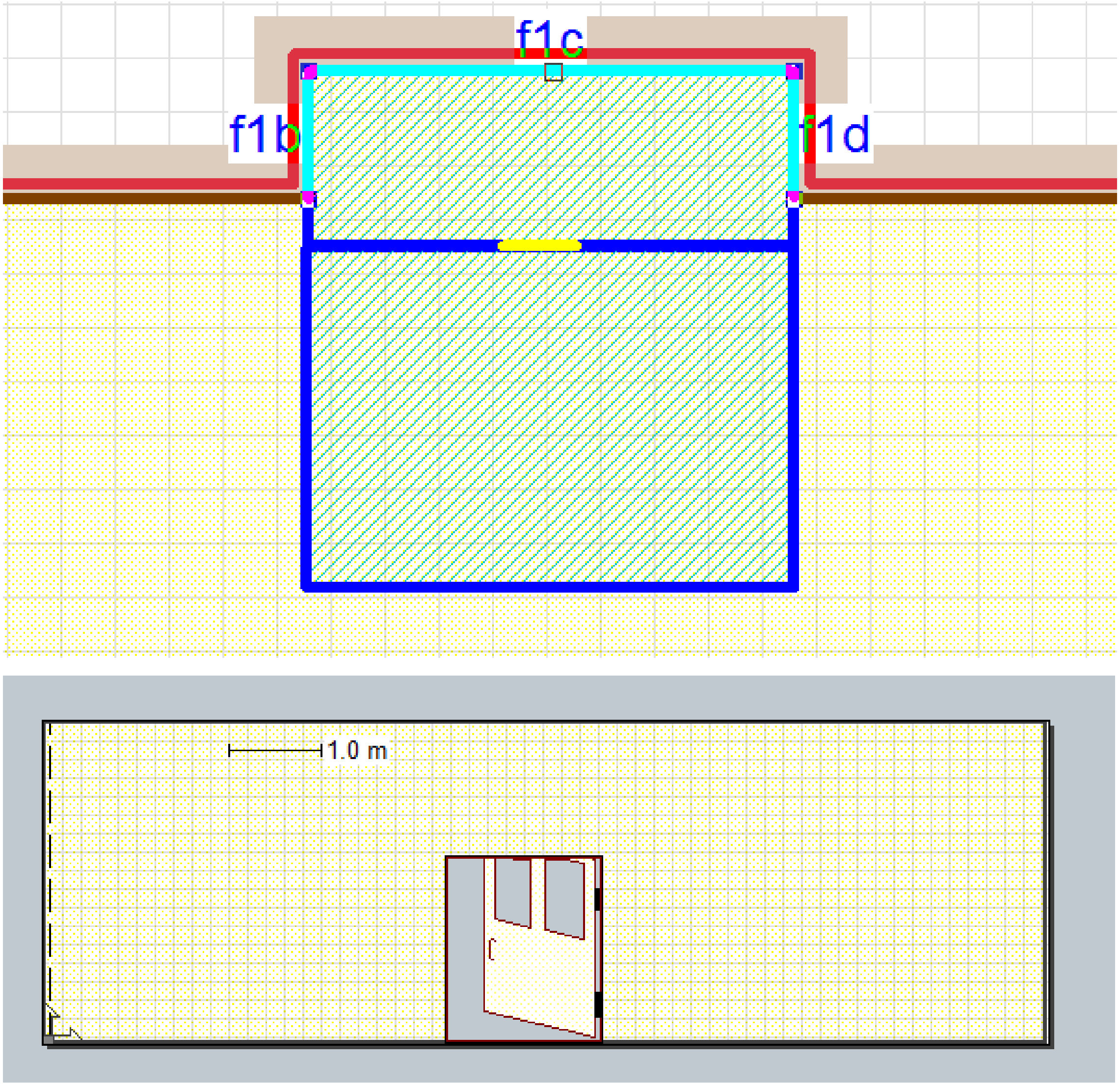


Figure 70. two zones with an opening simulation

Where is very important to define the model fidelity as a climate, and also orientate the building for the north and put some shading in the windows too. The reason is that IDA program automatically choose a south orientation and also don't understand if the weather is cloudy or not, with the excessive solar gain as it required.

Where the first zone corresponds for the near glass and the second one is the adjacent one. Zone 1 showed in (fig.71) and Zone 2 in the (fig.72).

Zone 1

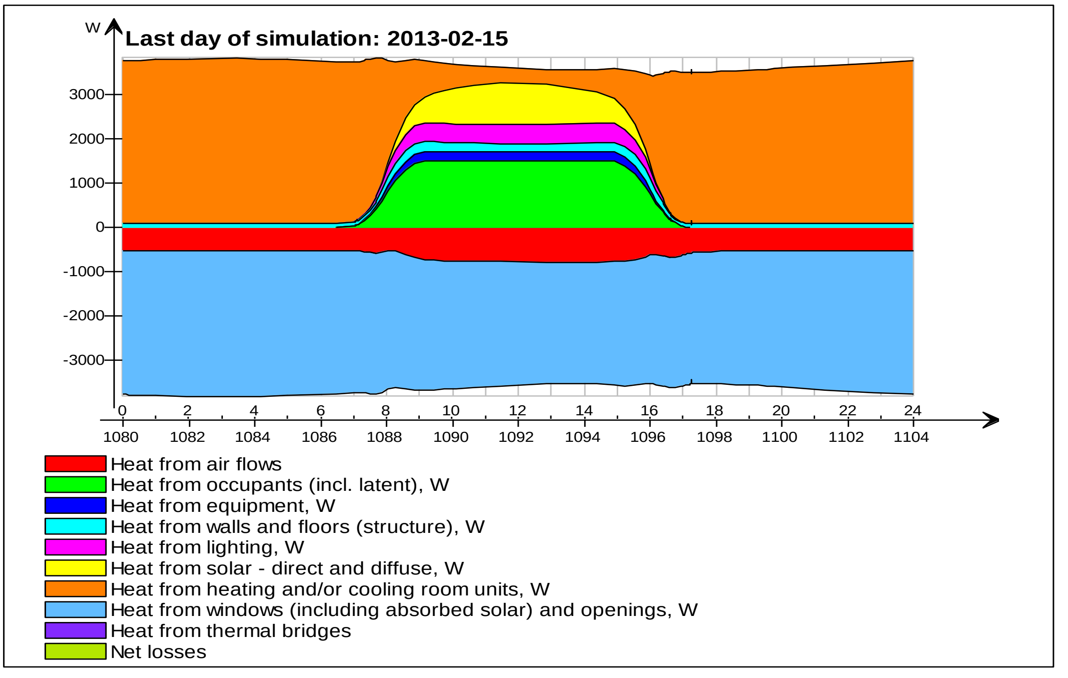


Figure 71. Zone 1. Near the window

Zone 2

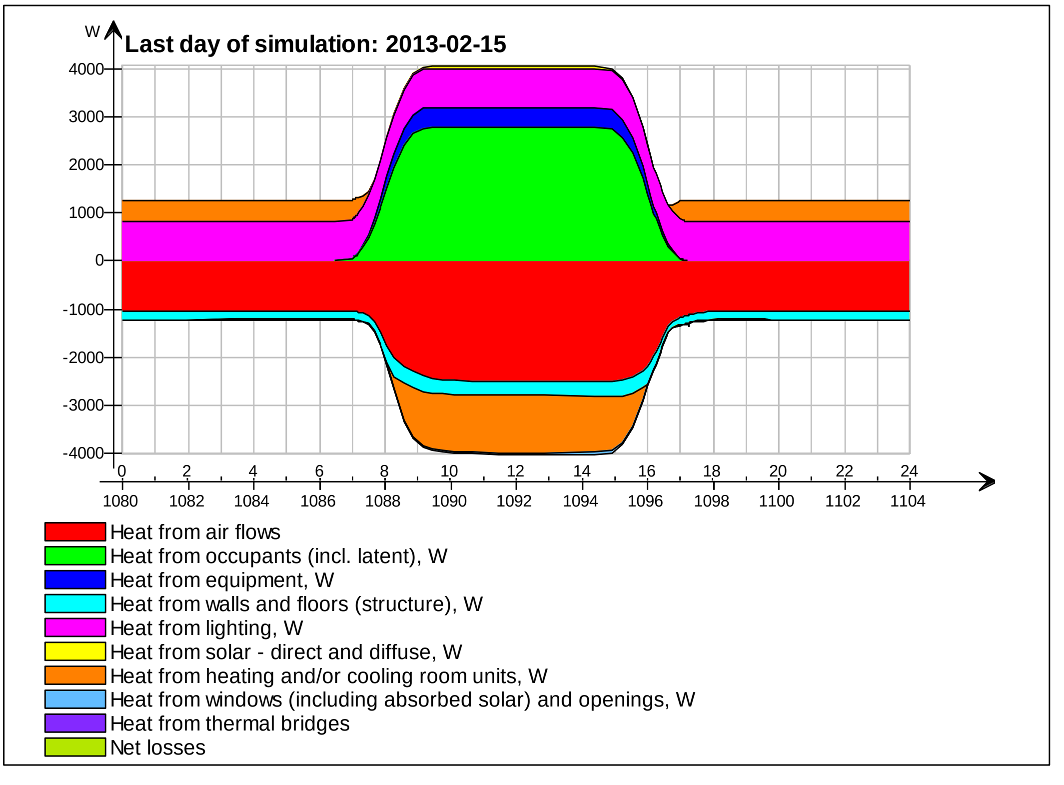


Figure 72. Defined zone 2

And where is clearly seen that in the first zone and as a closer of the window be, the heat losses through it is bigger, and as a consequence the heat demand to compensate this losses are so high. In the other hand, repairing for the zone two, it is shown that the heat demand is not as much as in the first zone, and the internal gains due to lighting, equipment and the occupants takes a big importance in the balance[37].

Therefore, it has been showed the building conventional windows are the problem for the thermal discomfort in the room, and thus, electric heated windows will be installed.

THERMAL COMFORT:

As a consequence of the heat distribution into the room, the thermal comfort for each occupant also varies depending on the place into the room that is situated.

Returning for the unique zone simulation used at first, two different points for the occupants will be placed into the room and different results will be expected then. See (fig.73)

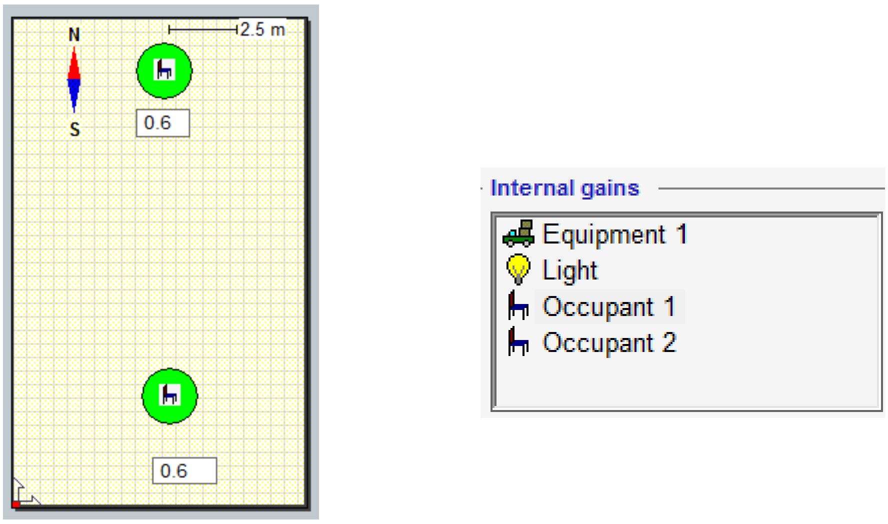


Figure 73. Two occupant position in the same zone

Both occupants will receive the same activity level and clothes parameters as the following IDA input (figure 74) shown:

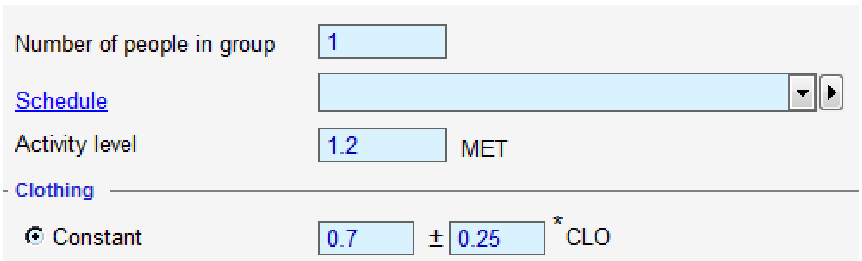


Figure 74. Activity level and clothing input

Following this method, different simulations are made with IDA program, and exactly in this project, the different positions shown in the (fig.75) are chosen. While southern occupant maintained as fixed, the occupant near the window will be changing the position in every case. Thus, the first case corresponds when the occupant is just in the corner between the windows, closer one for them, in the second case the occupant is situated around 2.5m far of the window and the last one is around 6m far, and as it can be in the following figures.

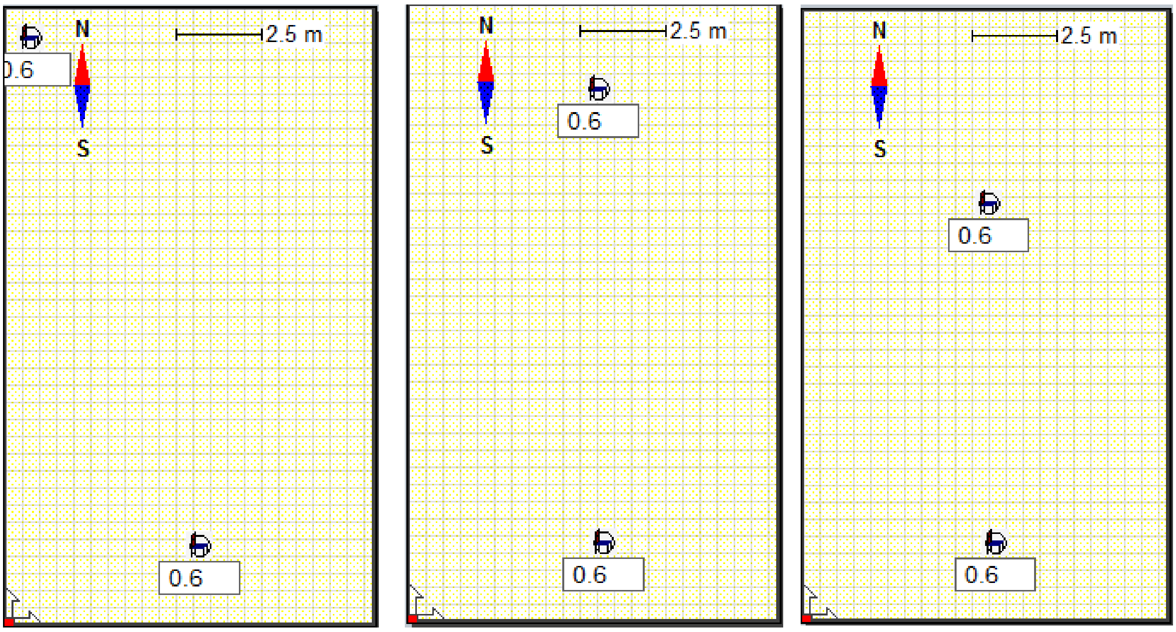


Figure 75. Three different positions for the occupants

Thereby, and taking into account the outside temperature for the simulation is around - 15C. More exactly, as the following graphic evolution shown: (fig.76).

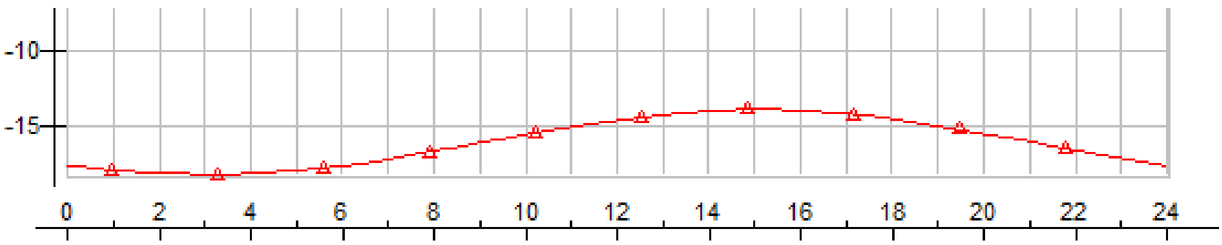


Figure 76. Outside temperature evolution during the day

The different thermal comfort results will be obtained for each case and as in the following resultant graphic will be shown. (Fig.77,78 and 79).

First case

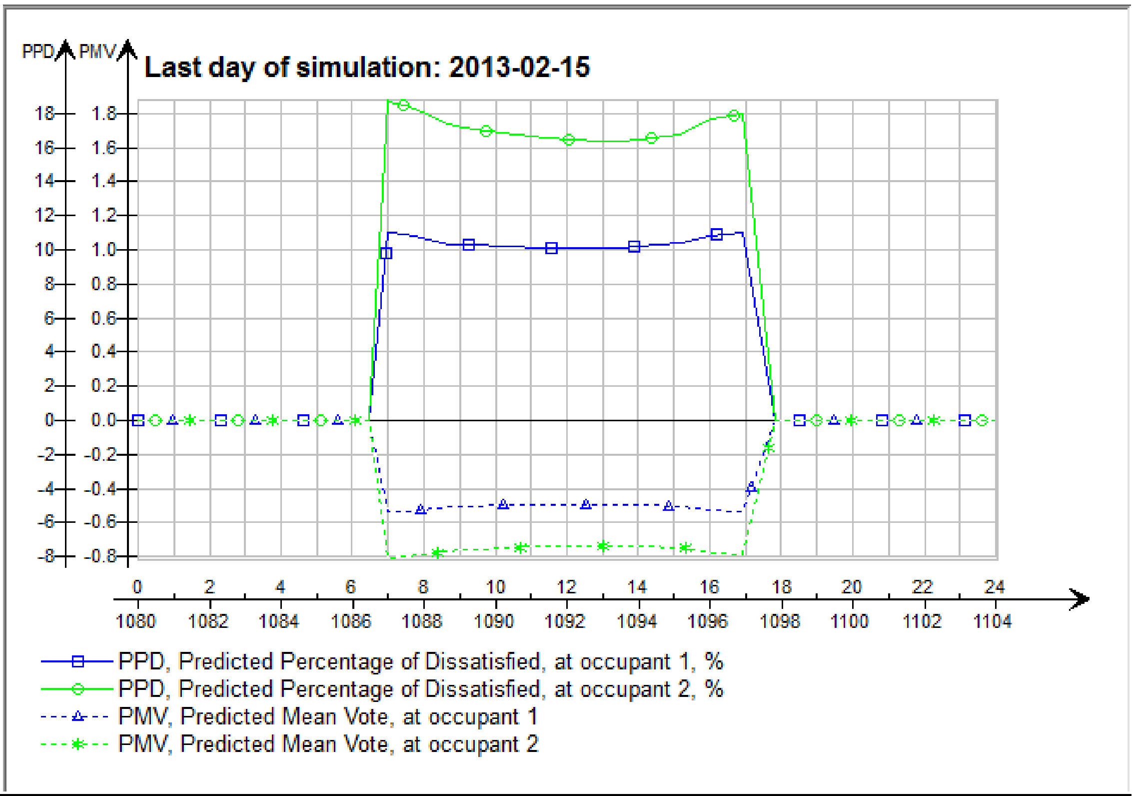


Figure 77. PPD results graphic for the first position for the occupant

Second case:

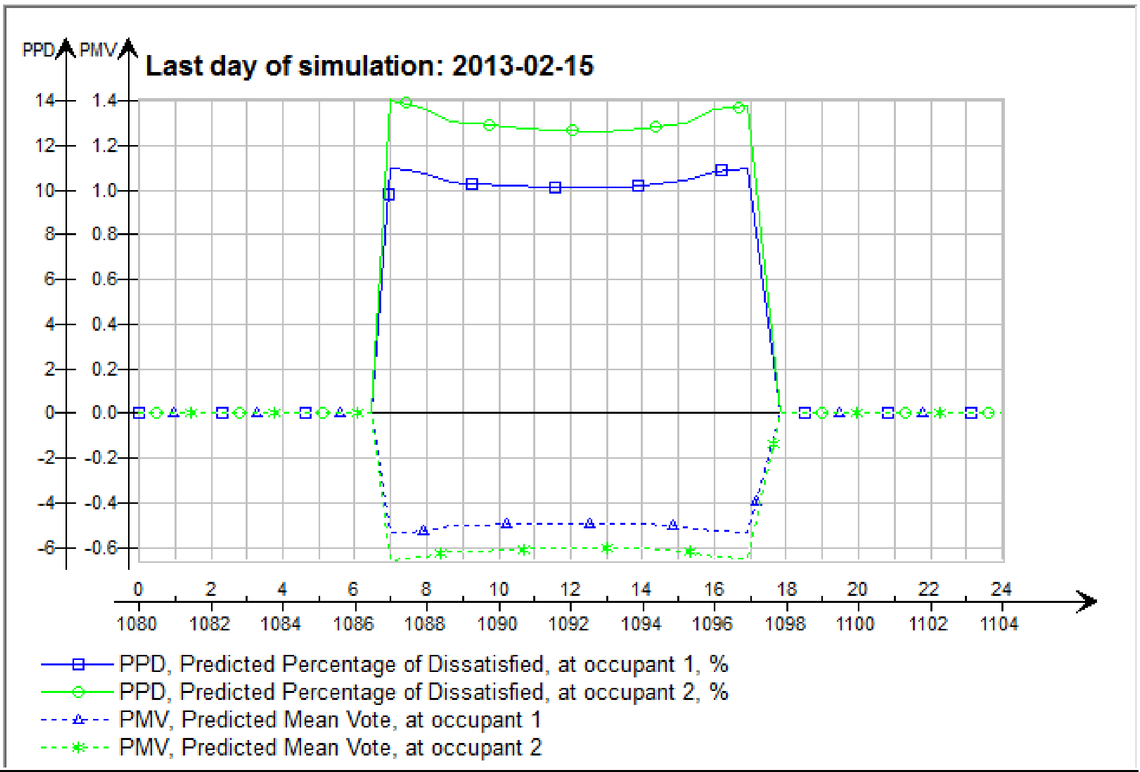


Figure 78. PPD results graphic for the second position for the occupant

Third case:

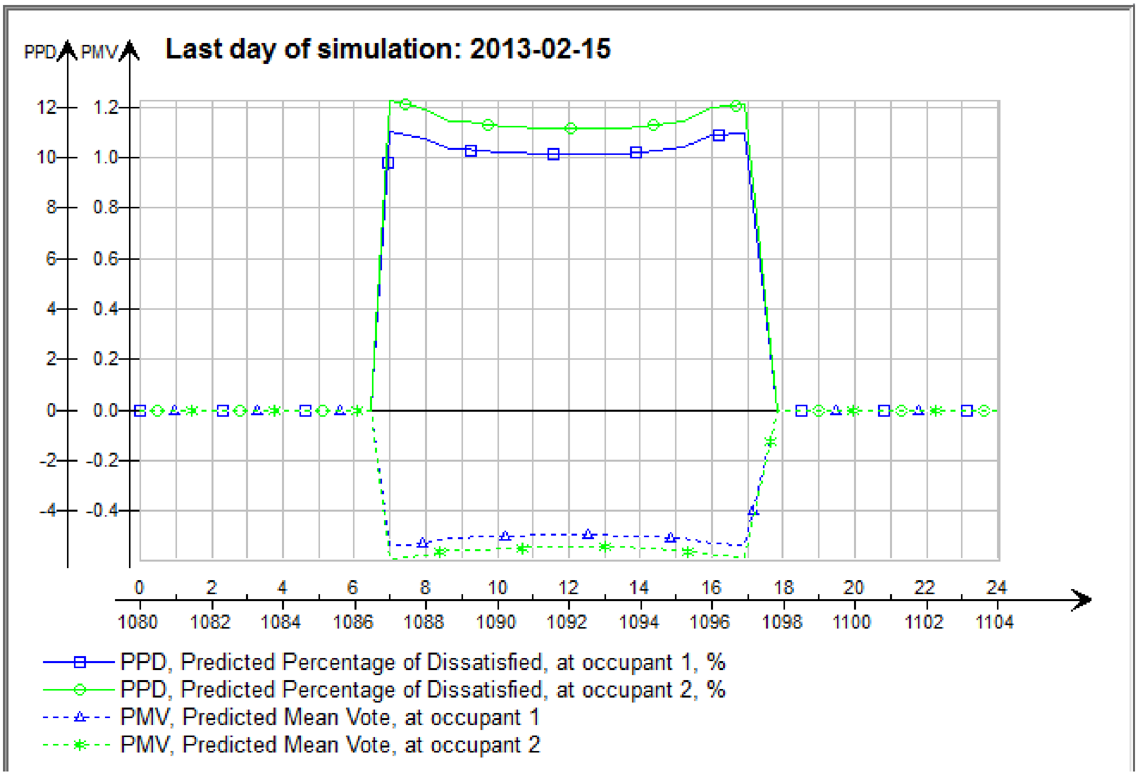


Figure 79. PPD results graphic for the third position for the occupant

As the results offer, while the comfort of the occupant in the bottom of the room is adequate and keep constant with a predicted percentage of dissatisfied (PPD) of 10%, the occupant moving to different positions show different values in the PPD. A **PPD** of around 16 to 18% in the first case, around 12 to 14 % in the second one, and around 10 to 12% in the third and last case simulated, showing a clearly deteriorate of the comfort as closer of the window is situated the occupant. *(Measured when the occupant is working, for 8:00 in the morning to 16:00 in the afternoon)*

In the other hand, the **PMV** predicted mean vote, is around -0.8 in the first case. In the second case this is -0.6. In the last case the PMV is -0.5. This means that the results obtained give a slight cool sensation to the occupants.

4.4. POSSIBLE SOULUTION FOR THE PROBLEM

An option of improving this thermal comfort values and disconformities into the room could be increasing the whole room inside temperature in one degree. From 22ºC to the indoor temperature of 23ºC.

In this case the distribution of the temperature into the room would be more uniform, and for sure the predicted percentage of discomfort will decrease significantly. Thereby, the simulation for the three analyzed obtained. See figure (80, 81 and 82).

First case

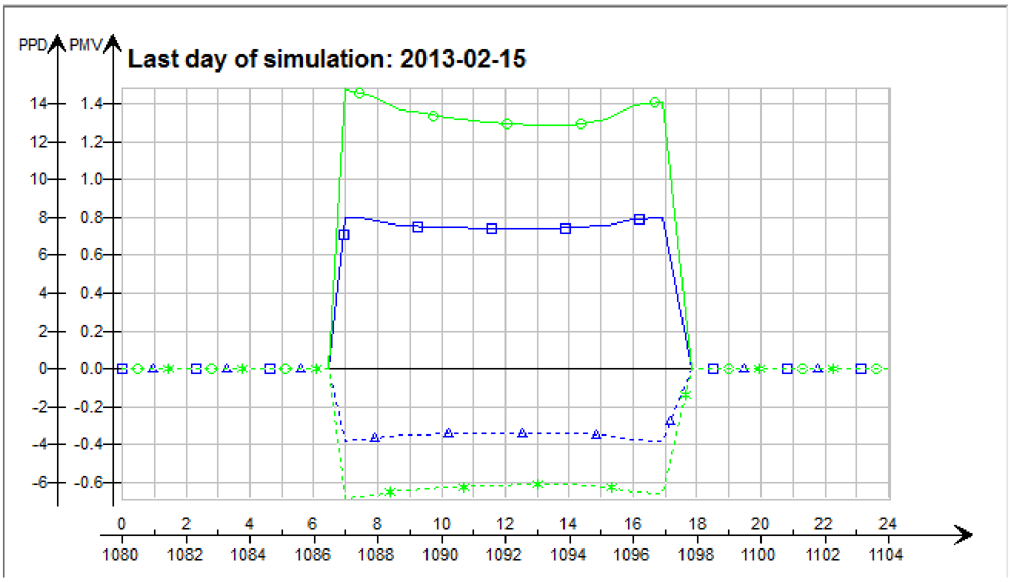


Figure 80. PPD evolution when increasing the room temperature 1 degree. First case

Second case

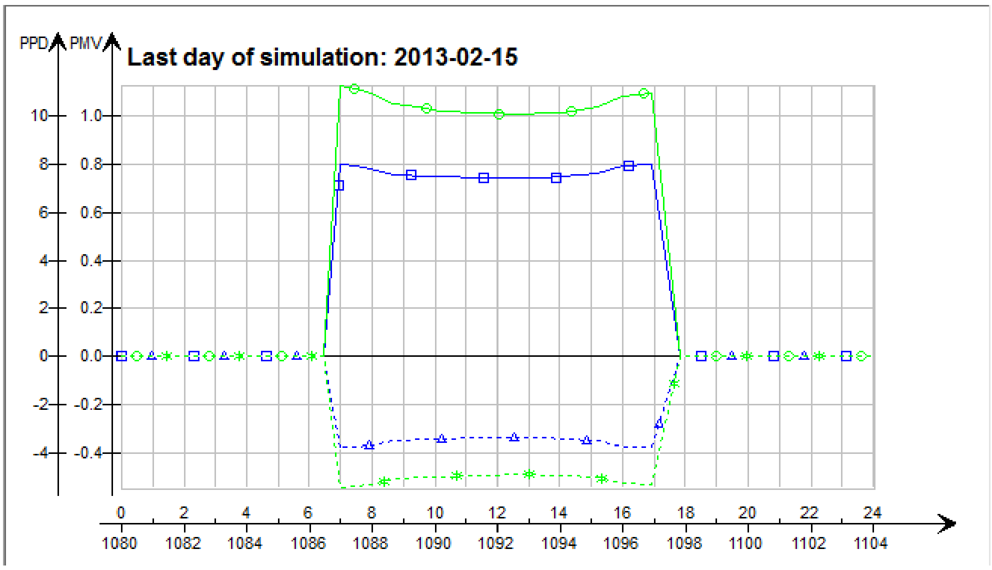


Figure 81. PPD evolution, when increasing the room temperature 1 degree. Case2

Tthird case:

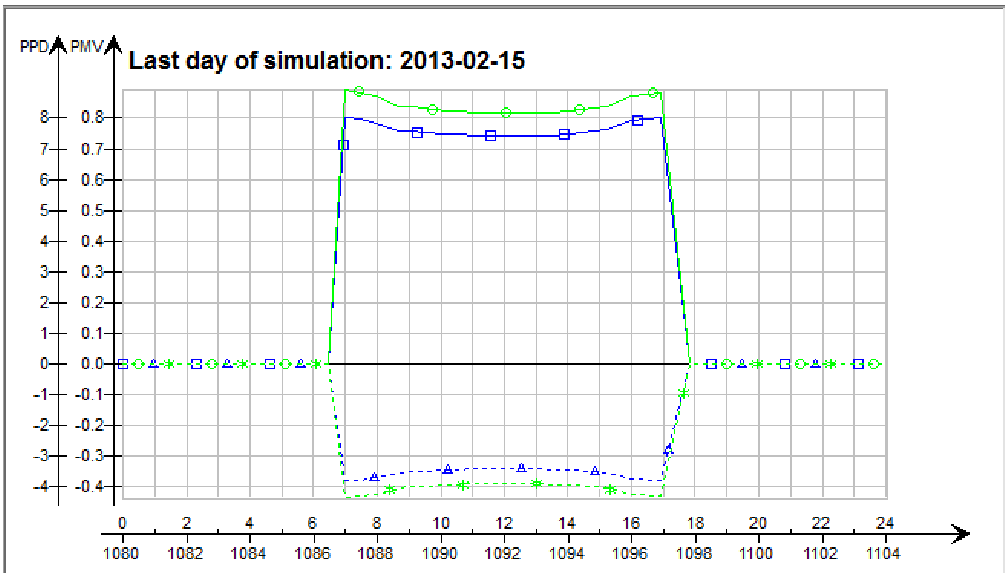


Figure 82. PPD evolution, when increasing the room temperature 1 degree. Case3

And where is easy to realize, that a maximum PPD of 13% situated just near the windows is obtained, improving the 16to18% that it is obtained before and for the first case. In the second case the PPD changes from 12-14% to be 10%, and in the last case, from 10-12% to a PPD of 8%. Thus, having better thermal comfort for the occupant.

For the energy aspects referred:

When the whole year simulation is made, the following energy results are taken and taken into consideration. See (fig.83).

		Delivered energy		Demand
		kWh	kWh/m^2	kW
	Lighting, facility	4073	21.0	1.95
	Electric cooling	1823	9.4	4.68
	HVAC aux	7211	37.2	0.86
	Electric heating	35129	181.1	14.0
	Total, Facility electric	48236	248.6	
	Equipment	2026	10.4	0.97
	Total, Tenant electric	2026	10.4	

Figure 83. Energy results for the simulation by IDA

Thereby, the energy needed for increasing one degree the temperature is:

E=(35129kwh-31964kwh)=**3165KWh**

That it will suppose a really increase in the energy demand and the increase in the energy bill of the company too.

4.5. ELECTRIC HEATED WINDOWS USED

The cold windows with a low *U*-value have always caused drafts and asymmetrical radiation, even more when the glazing area is higher. In this case, where the glass surface area is around $57m^2$, even radiators positioned on the floor cannot stop the formation of drafts and thus, in a cold climate like here in Sweden, warm window surface presents unique possibilities for thermal conditioning. Thereby, electric heated windows are installed for improving thermal comfort near glazing. See (fig.84).

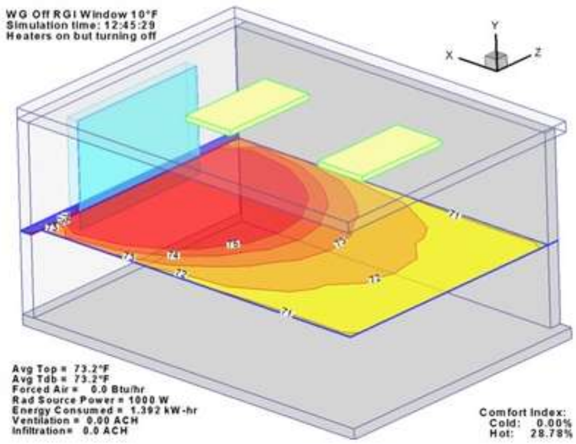


Figure84. Electric heated windows, transfer of heat [2]

However, and as in this case happen, the electric heated windows are usually used as comfort device, it means it doesn't replace other heat sources. Exactly in this case, whole building are heat by the ventilation system (HVAC), to 22ºC as indoor comfort temperature and electric heated windows will be used at the same time. Thus, both systems, one use district heating grid source and the other for the electricity network, are designed and connected each other for improving thermal distribution in the whole room. As the following (fig.85 and 86).

Fig.85.heater unit in the ventilation system[38] *Fig.86.electric heated windows[39]*

Contracted company

Electric window installation in the building will be carried out by a Swedish company called **Cl Specialglas.** They make the product, offer technical support and electrical schema and helps the end customer to achieve the number one glass solution as well[34].

Company brief description: specialglas company is specialized in advanced glass constructions and the supply to different market segment. With more than 25 years experience with the heat glass construction, is the leading company in heated glass in the Nordic region.

Warm glass offered by the company

-Is designed on request, max size 2170x4000 mm, min size 120x260 mm.

-It offers different possibilities of window panes thickness and the gas inside, as the following table shows, (fig.87).

Yttre glas	med klarfloat		SGG PLANITHERM ULTRA N	
Inre glas	SGG EGLAS (härdat)*			
Uppbyggnad	4-12-4	6-12-6	4-16-4	6-16-6
Dagsljus (EN410)				
Ljustransmission LT%	75	73	73	71
Reflektion utvändig LR%	17	17	15	14
Reflektion invändig LR%	16	16	14	13
Solenergi (EN410)				
Primär transmission %	59	54	47	44
Reflektion %	15	14	24	22
Absorbtion - Yttre glas %	11	15	20	24
Absorbtion - Inre glas %	0,40	0,41	0,33	0,28
Solfaktor EN410 / ISO9050M1	0,72	0,68	0,55	0,53
U-värde W/m²K (EN673)	1,6	1,6	1,1	1,1

Figure 87 . Specialglas Swedish company, windows catalog table [34]

Control: Hot Glass regulated by different types of control equipment handles the glasses automatically. Easy, energy efficient and reliable.

Power: Between 50-400W/m^2. Normally about 5-10W/m^2 over the year to room temperature on the glass.

Technology: CL Special Glass Ltd helps with sizing, suggestions for engagement and support at all installations.

Construction Methods: Hot Glass can be used in traditional facade systems, structured glazing, fixed and opening windows and the sliding doors.

(Production according to EN12150, ANSI Z97.1-1984, ISO 613)

The chosen windows characteristics

The windows installed in the building, corresponds with the 4 column of the table shown before. It consists of **6 mm thickness double glazed pane**, with a transparent high resistivity coating applied in the inner pane. As it it seen in the (figure 88). The coating is fully invisible and it doesn't need of any particular care or maintenance, this transfer heat to the inner heatable pane, that is tempered and could rise its surface temperature even up to 30 ºC In addition, the filling between the glasses is **16mm of argon gas**, for proportioning a better U-value, trying to stop the convection losses there exist.

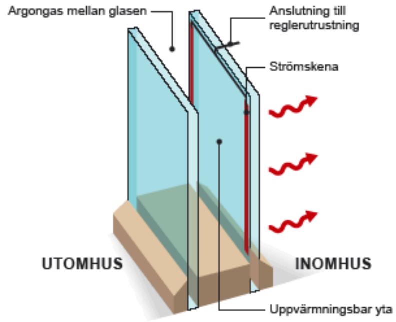


Figure 88. Electric heated window[34]

U-value of the window:

The U-value of the electric heated window is not fixed like in a conventional window happen, in this case it depends of the panes surface temperature that is a variable parameter and depends if the window **is switch on** or not. If the weather is cold and a higher power of the windows are required for heating, the window will provide a higher heat transfer to inside room, but however the heat transfer from outside(the heat losses), will be higher too at the same time. This means, that the U-value of the window is now bigger too, that it isolate less than when the window is in off. Thus, ↑↑ Power output → ↑↑ losses→ ↑↑ U-value.

Another thing to take into consideration is the window structure and the form to connect the cables for supplying the electricity for the coating.

Electric connection:

1-In the case of the direct connection to the glass, see (fig.89), the U-value only depend of the glass U-value changing with the surface temperature.

2-However, in this case, the **electricity connection is made in the window Aluminium frame**, that is a good electricity conductor material, but also good heat transferring material and thus, increasing the whole window U-value. See (fig.90).

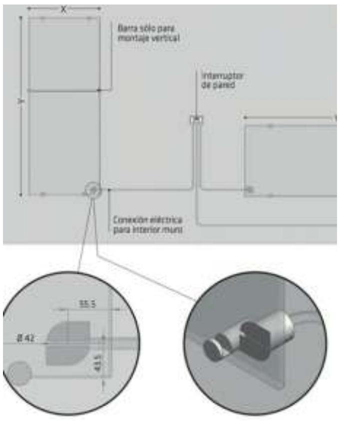


Fig.89. Direct electric connection [27]

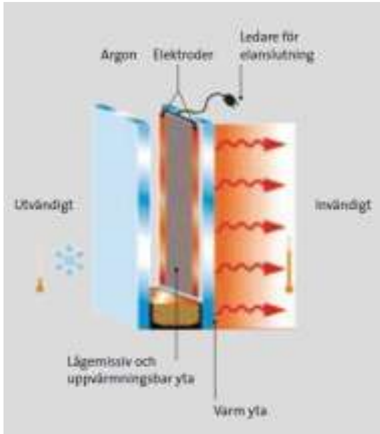


Fig.90. Electrode connection for the glass[34]

Thereby, the window chosen to install in the building has an initial value of 1.1 $\frac{W}{m^2K}$, but as it has been explained, considering the aluminium frame effect, the U-value will increase to 1.5 $\frac{W}{m^2K}$. However, don't forget that depending of the electric power output needed in each time, the U-value of the window will be changed.

$$\textbf{U-value} \geq \mathbf{1.5}\ \frac{\boldsymbol{W}}{\boldsymbol{m^2K}}$$

Other important Characteristics:

Daylight (EN 410)

-Light transmission: 71%

-External reflection: 14%

-Internal reflection: 13%

Solar energy (EN410)

-Primary transmission: 44%

-Light reflectance: 22%

-Outside pane absorption: 24%

- Sun Protection Factor 71%

-working surface temperature is typically in the range of 20ºC to 30ºC.

- Normal power from 50 to 400 W/m^2. Properties (CEN standard) The Maximum of 400W/m^2 gives when the voltage applied is 230V (AC), then using the transformer to reduce and regule the voltage values applied to the glass electric connection, the power output will change for a minimum of 50W/m^2.

4.6. COMFORT IMPROVEMENTS

When electric heated windows are finally installed it carries with him positive aspects in the thermal comfort for the occupants. For show this positive improvement, IDA program is used again, and the results will be compared with the others obtained when the electric heated windows were not installed yet.

IDA simulation:

For the simulation of the electric heated window, several different methods have been used during this project. As it has been said, there is not an option to connect in the program one electric heated window, and thus, the different cases should be analyzed in order to imitate their influence in the results. Then, the better choice will be taken into consideration and will be compared in the results part of the project.

First simulation:

For the first option, a simple wall with the same U-value of the electric heated windows is chosen, with a possibility to give it the different temperature values. Thus and with a determinate surface temperature known, the thermal comfort indexes values could be obtained for the two occupants. (fig.91). However, this first option is not given any changes in the comfort aspect when simulated by IDA, that may be due to a defect of the program, or simply that it is not programmed for this finality, so another alternative should be used as the solution.

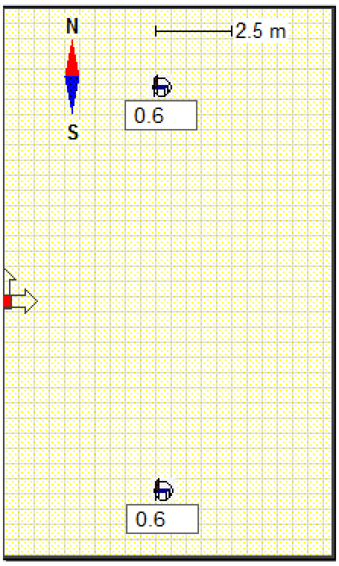


Figure 91. Position for the occupants, in simulation 1

Second simulation

In this case, another room has been designed and added for the working area. Exactly where the electric heated windows would be installed and as it can be seen in the following (fig.92).

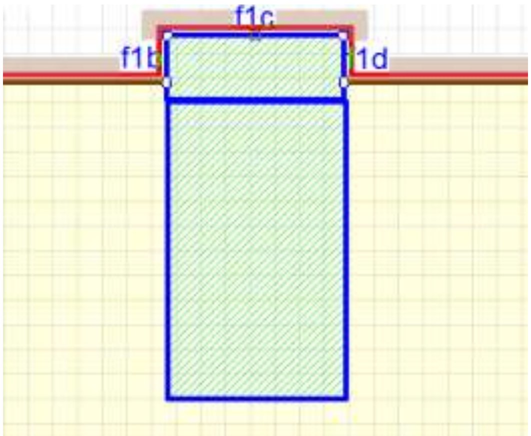


Figure 92. created two zones for the simulation

Again for the north situated wall, the same U-value as the electric heated windows, U=1.5W/m^2K, will be given and the rests of the parameters will be introduced for the working area referred, as the indoor temperature of 22ºC. However, with the small room that has been added above, different indoor temperatures will be chosen to it.

The reason for using these two different rooms is clear. Given a determinate temperature for the small room; it will be known the heat transferred by the wall.

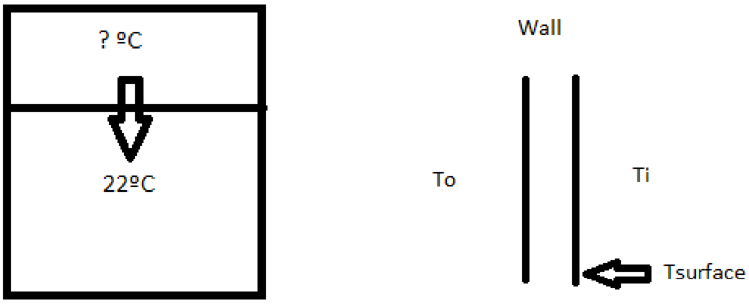


Figure 93. Explanation pictures

The following equation could be written as:

q= U.A. (Ti – To) = $\frac{1}{Rsi}$**. A. (Ti- Ts)** (eq.16)

Where:

U: correspond U-value(W/m^2K)

A:area

Ti=indoor room temperature

To=outdoor temperature

Ts= surface temperature.

Rsi=indoor thermal resistance, with a standard value of 0.13m^2K/W

Therefore, controlling the indoor temperature (Ti) that is 22ºC, but also the outside temperature (To) that in this case corresponds for the small room; the surface temperature of the wall could be also controlled for the following different simulations. The wall with the U-value of 1.5W/m^2K, will be in this case the electric heated window and the working temperature of it will be introduced by controlling as it has been explained, with the small room indoor temperature value.

For instance, when the window is working at a surface temperature of 20ºC:

$$\mathbf{q= U.A.\,(Ti - To) = \frac{1}{\mathit{Rsi}}.\, A.\,(Ti- Ts)} \qquad \text{(eq.16)}$$

$$1.5.\,(22ºC\text{-}To) = \frac{1}{0.13}.(22ºC - 20ºC) \;\; \rightarrow\text{resolving:} \quad To=11.74ºC$$

The simulation will be made maintaining an indoor temperature around 11ºC for the small room added, and the following thermal comfort indexes are obtained, (fig.94):

-window at 20ºC:

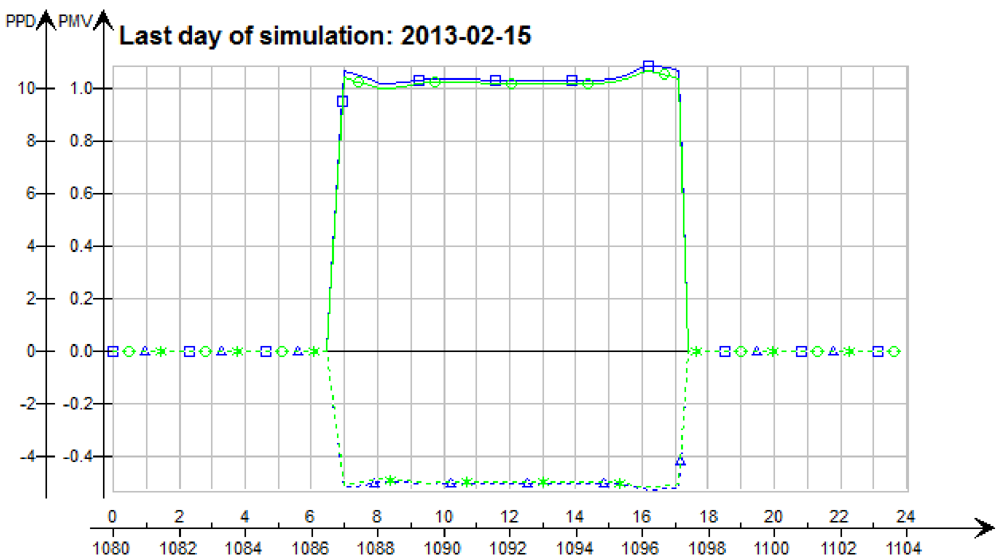


Figure 94. "predicted percentage of dissatisfied"(PPD) evolution. Window at 20ºC

As it is seen, both occupants would have the same PPD around 10%, result that could be possible due to the window surface to 20ºC and the whole room temperature of 22ºC are similar.

Following the same process, but in this case when the window is working at 23ºC.

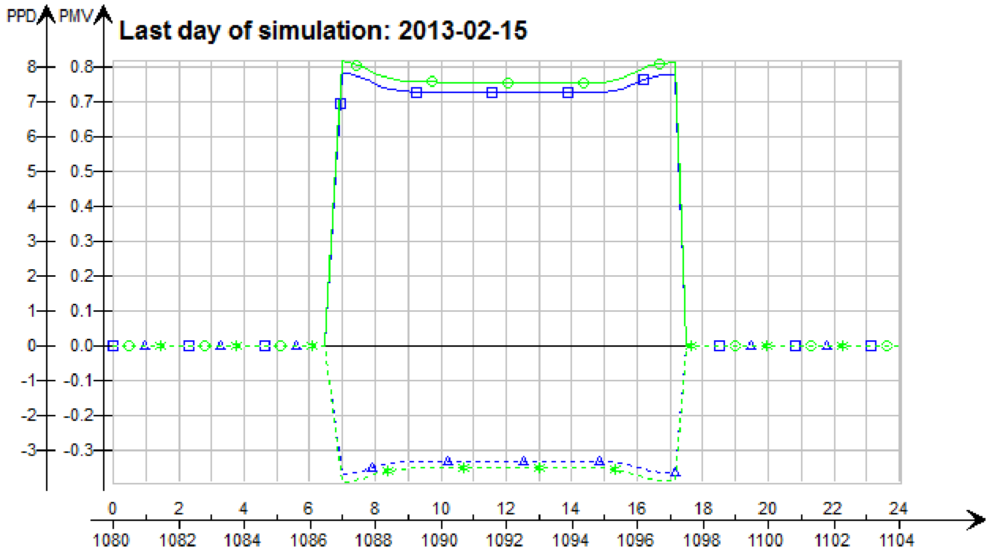


Figure 95. "predicted percentage of dissatisfied"(PPD) evolution. Window at 23ºC

Finally, working at the maximum power of 400W/m^2, with Tsurface of 30ºC :

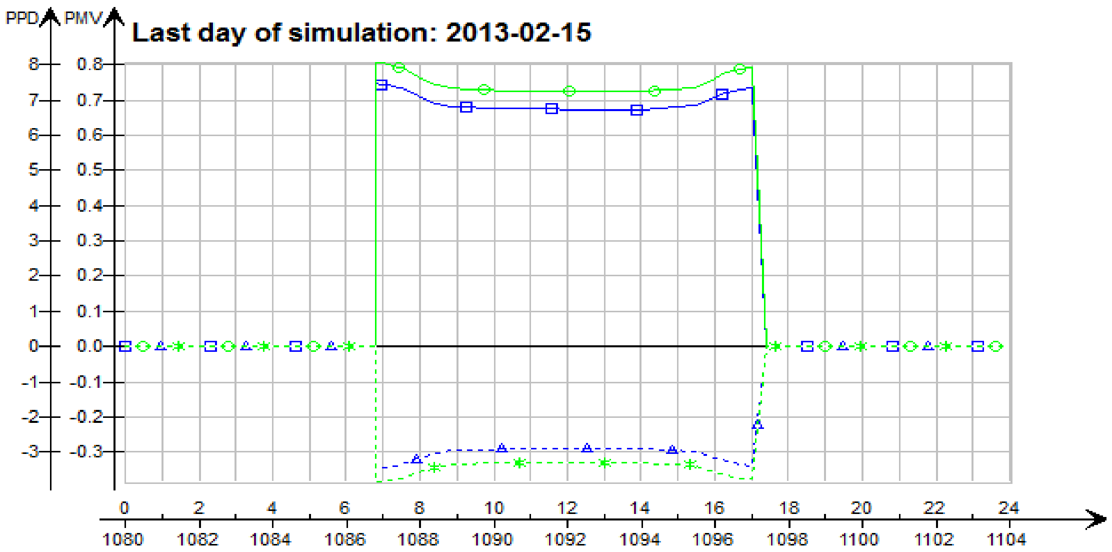


Figure 96. "Predicted percentage of dissatisfied"(PPD) evolution Window at 30ºC

As the window surface temperature increase, it could be seen an improvements in the corresponding predicted percentage of dissatisfied. However in all the cases, both occupants have almost the same PPD value that is not totally true at the same time. Therefore, the method used will not consider as the totally correct ones.

Third and the definitively option:

For the last simulation with the IDA program, an electric radiator is added under the window, and different power values are given to it in order to simulate as the different surface temperature of the window. See (fig.97).

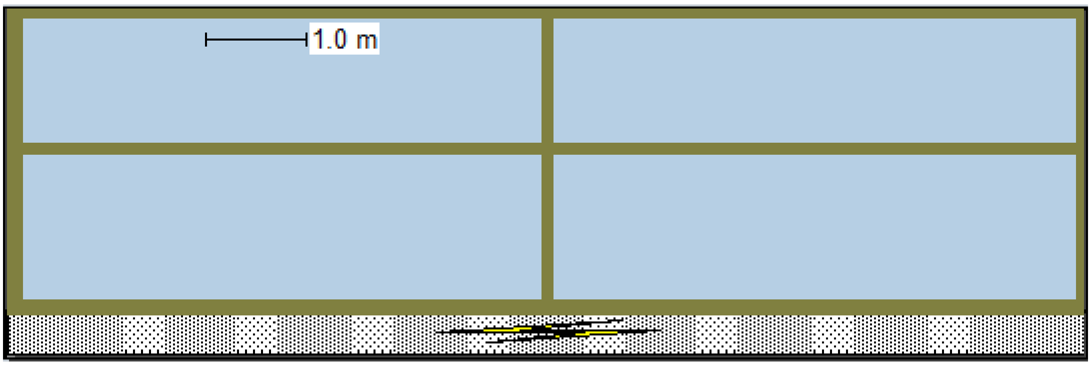
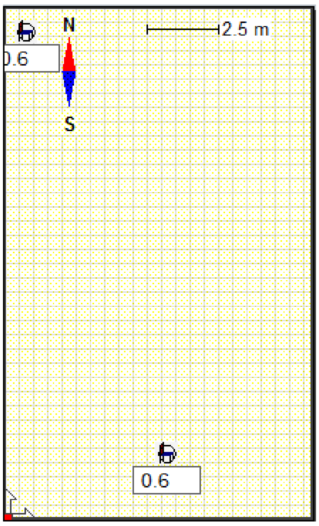


Figure 97. Electric radiator under the window

Two of the three different positions for the occupant used in the section, “4.4 thermal comfort differences into the room” when the electric heated windows were not installed yet, will be again simulated (fig.98) and thus, new thermal indices are obtained. That will mostly depend on the power introduced for the radiator.

As it is known, the electric heated windows usually takes a temperature between 20ºC and 30ºC, for the input power of 50 W/m^2 and 400W/m^2 respectively. Thereby, and considering this relationship for a constant outside temperature of minus 15ºC, a window surface temperature of 20ºC, 23ºC, and 30ºC will be simulated. The method is easy to understand; the electric radiator installed under the windows will provide all the power output that the 57m^2 of the electric heated window would be providing at.



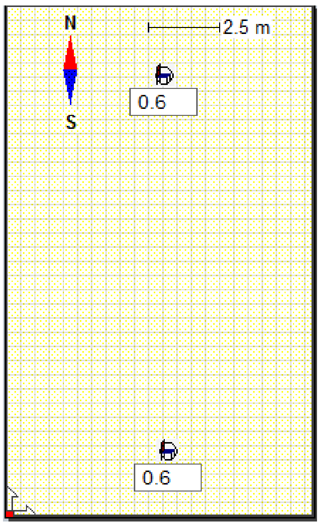


Figure 98. Occupants position

For the first case:

-When the window is in **off**. See (fig.99).

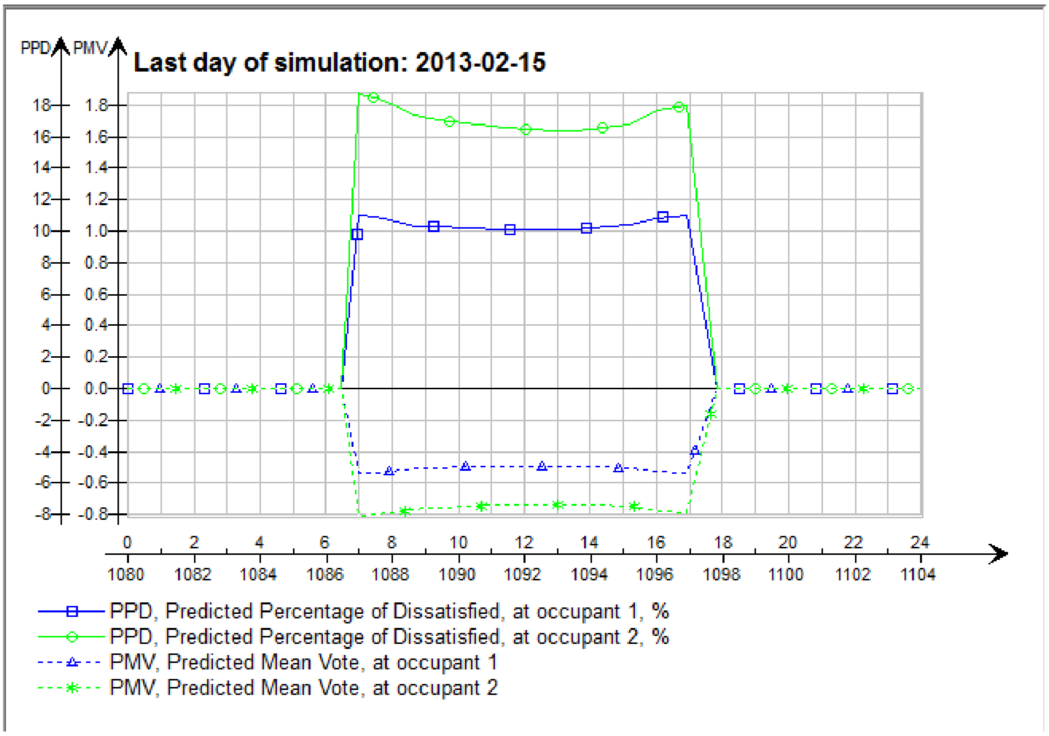


Figure 99. "predicted percentage of dissatisfied"(PPD) evolution. Window off

--For a 2850W radiator power, equibalent for a **20°C** surface temperature. (fig.100).

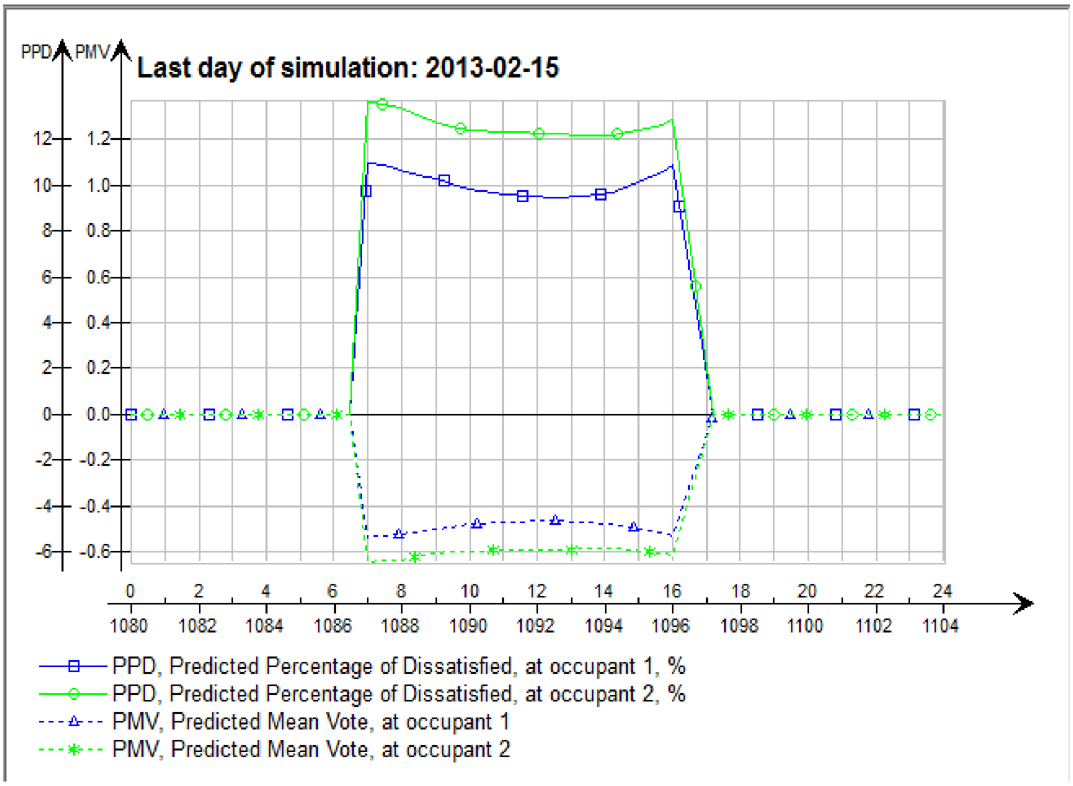


Figure 100. "predicted percentage of dissatisfied"(PPD)evolutione. Window at 20ºC

-For a 8835W radiator power, equibalent for a **23ºC** surface temperature. (fig.101).

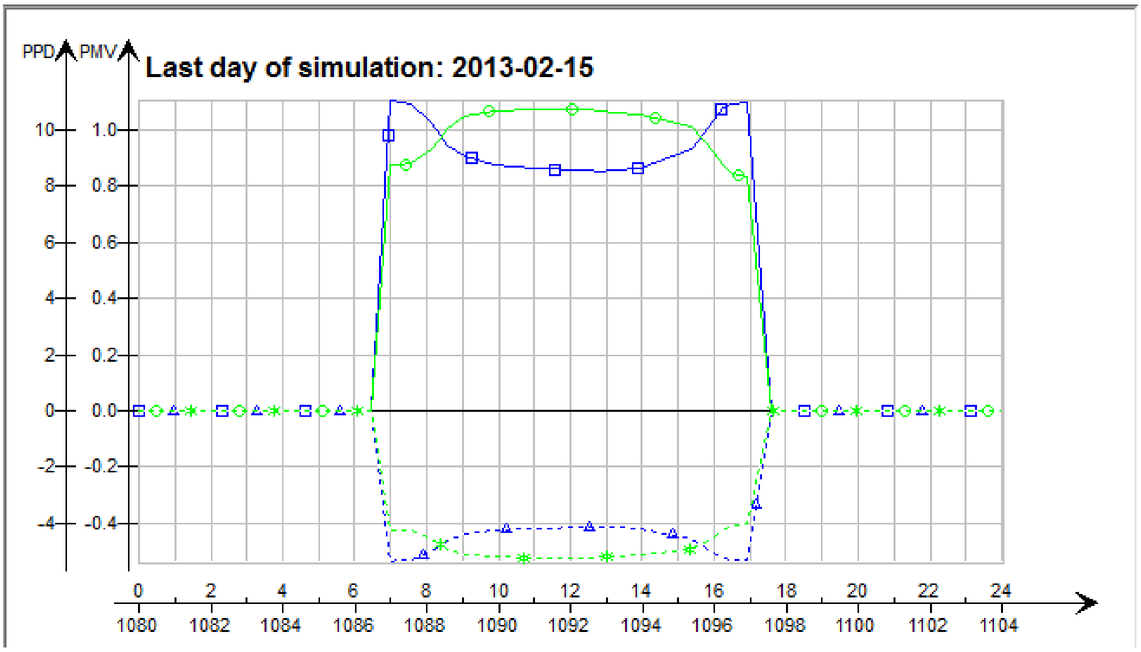


Figure 101. "predicted percentage of dissatisfied"(PPD) evolution Windows at23ºC

-For a 22800W radiator power, equibalent for a **30ºC** surface temperature. (fig102).

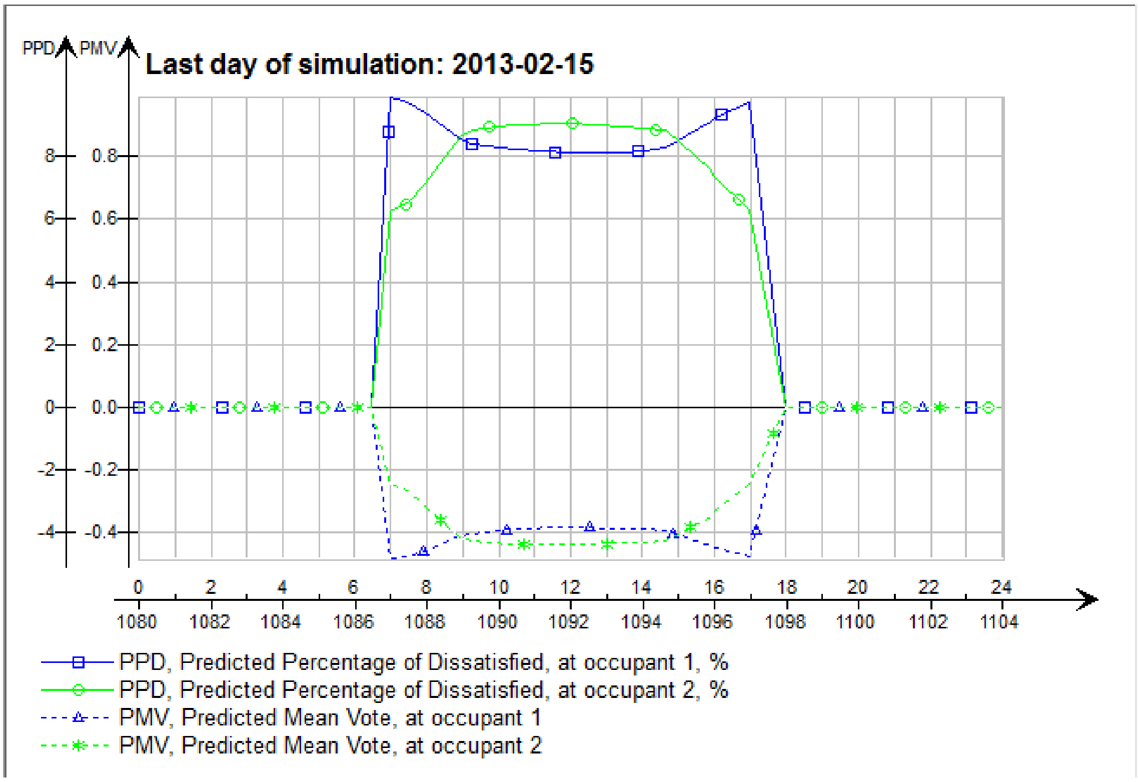


Figure 102. "predicted percentage of dissatisfied"(PPD)evolution. Window at 30ºC

Second case

-When the window is in **off**. See (fig.103).

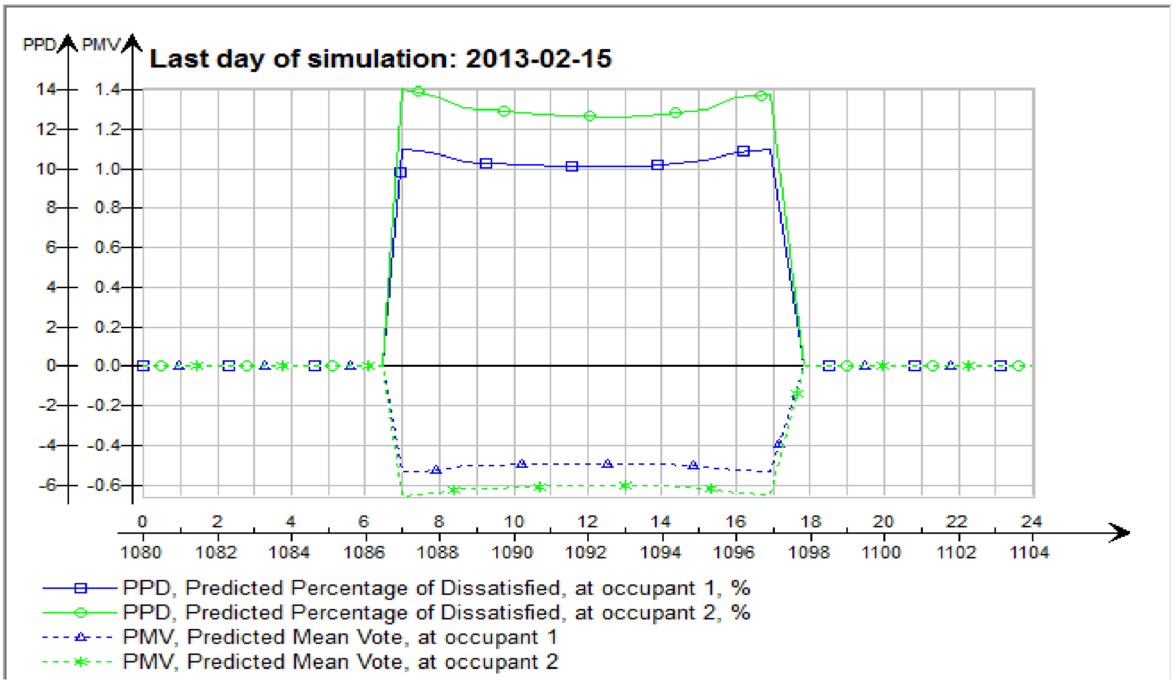


Figure 103. "predicted percentage of dissatisfied"(PPD)evolution.Windows off.

-For a 2850W radiator power, equibalent for a **20ºC** surface temperature. (fig.104).

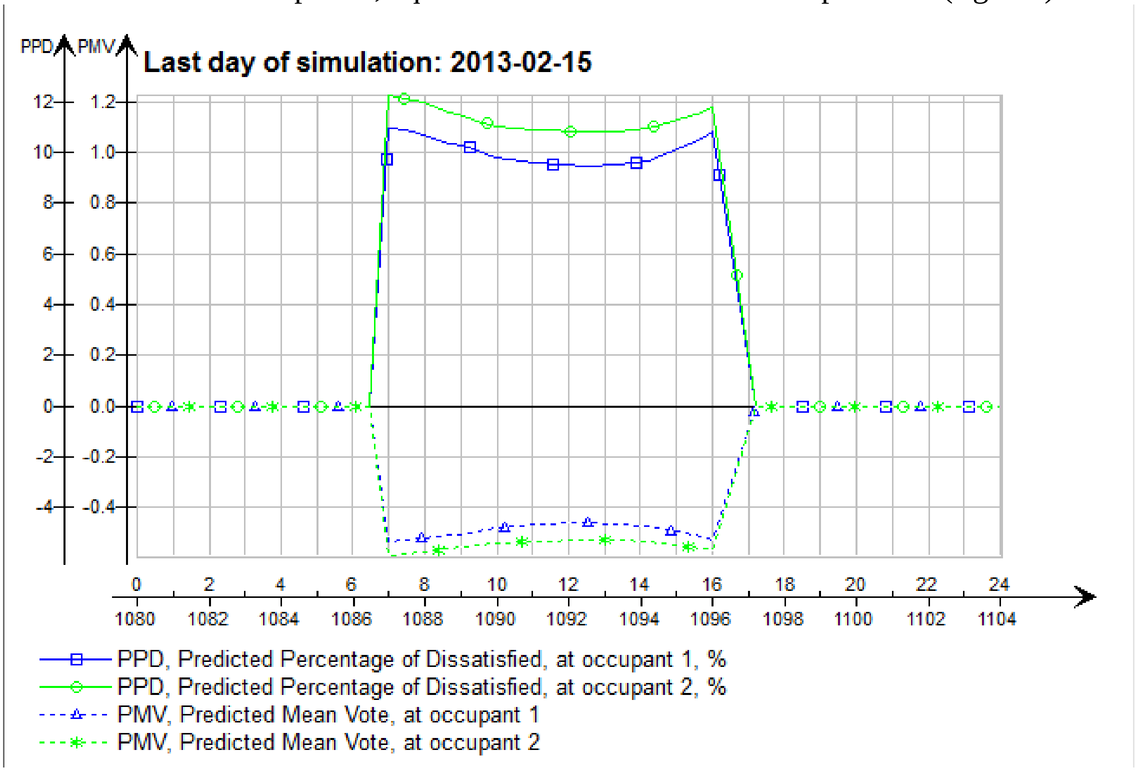


Figure 104. "predicted percentage of dissatisfied"(PPD)evolution Windows at 20ºC.

-For a 8835W radiator power, equibalent for a **23ºC** surface temperature. (fig.105).

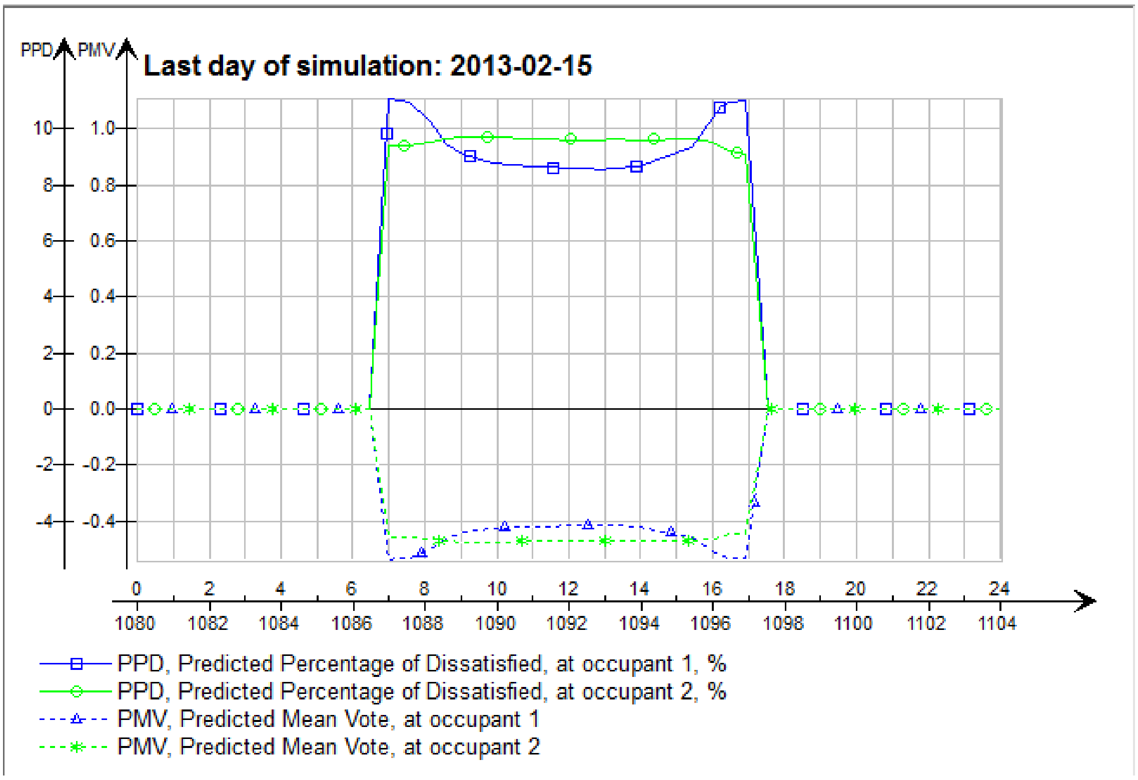


Figure 105. "predicted percentage of dissatisfied"(PPD)evolution Windows at 23ºC

-For a 22800W radiator power, equibalent for a **30ºC** surface temperature. (fig.106)

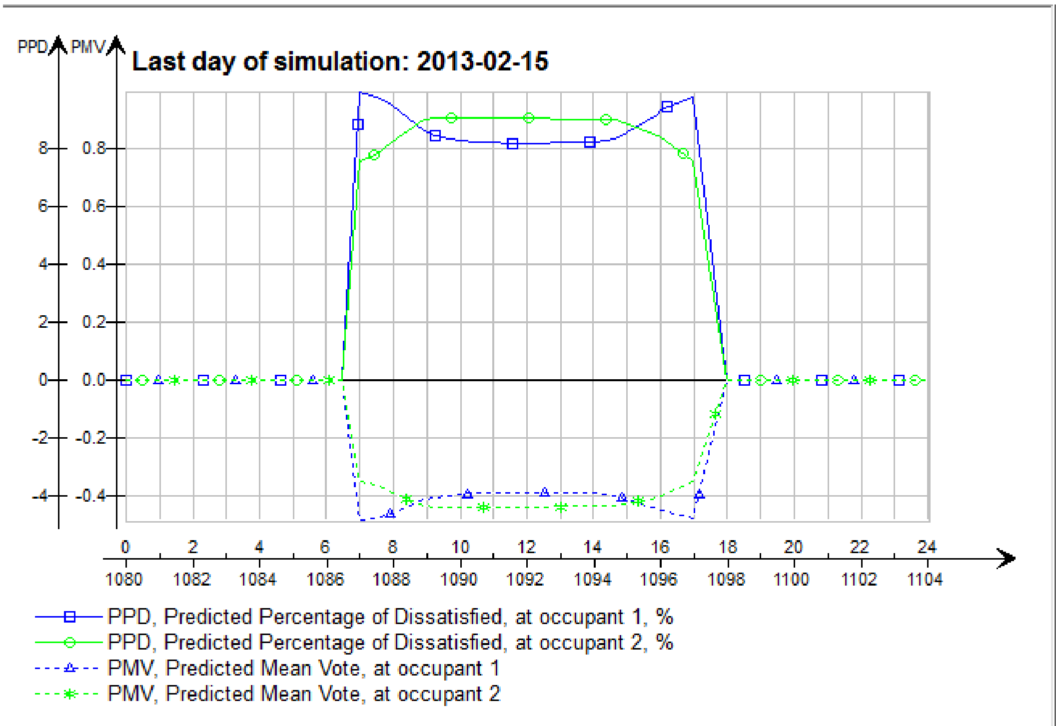


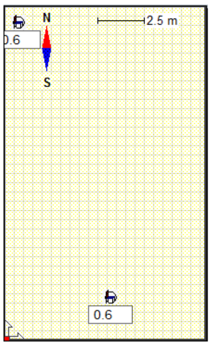
Figure 106. "predicted percentage of dissatisfied"(PPD) evolution. Windows at 30ºC

Analysis

As a summary as the graphics obtained, the following excel tables show the variability in the comfort indices for the occupants, depending of the window surface temperatures.

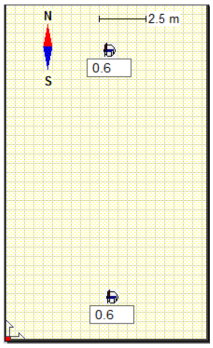
Fist case

	OCCUPANT 1		OCCUPANT 2	
	PPD	PMV	PPD	PMV
Off	16	(-)0.8	10	(-)0.5
20ºC	12	(-)0.6	10	(-)0.5
23ºC	10	(-)0.5	9	(-)0.4
30ºC	9	(-)0.4	8	(-)0.4



Second case

	OCCUPANT 1		OCCUPANT 2	
	PPD	PMV	PPD	PMV
Off	13	(-)0.6	10	(-)0.5
20ºC	11	(-)0.5	10	(-)0.5
23ºC	10	(-)0.5	9	(-)0.4
30ºC	9	(-)0.4	8	(-)0.4



As it can see here, the higher difference in the PPD, PMV variations occurs when the window is complete switch off and when is working with the lowest level of functionality, as 20ºC. In this range and for the first case simulated, the predicted percentage of dissatisfied varies from 16% to 12 %, while in the second case changes from 13% to a predicted percentage of dissatisfied (PPD) of around 11%. This shows that normally the windows surface is the colder part of the room and as a similar temperature as the rest of the room is given to it, the heat losses through it will decrease clearly. The heat losses through a material can write as Q=U.A.ΔT, so in this case the temperature between the window surface and the rest of the room will become similar and the heat into the room will maintain more uniform and constant.

4.7. RESULTS ANALYSIS

With the problem of the cold air drafts through the window in the building company and the thermal discomfort problem with the occupants mostly near the window, but also the comfort differences into the room, electric heated windows is chosen like an alternative for the solution for this problems. Anyway, during this project two possible alternatives have been simulated as the solution for the thermal disconformities. In the first option that is calculated, the indoor temperature in the room will be increased with one degree Celsius. The second option that is calculated, the option that is chosen for Sandvik Coromant, there will be electric heated windows installed. Thereby, energy consumption and the thermal comfort aspects are showed and compared between them.

Need of energy:

The easiest way is to increase the temperature in the room with one degree Celsius. In this way the demand of energy increases with **3165 kWh** during the year. This is around 9% of the total energy usage. The energy consumption of the electric heated windows can be higher than the first option. This depends on the working level of the electric heated windows. However, if the window power input is adequate chosen depend of the outdoor temperature but also on the indoor activity level, internal heat generation and solar gains through the window, could be even need less energy for a better comport aspects for the occupants. As simple as put thermal sensors in strategy situated points and use a central control unit could be the solution, giving the access also for the people working in the offices to change and varied the window surface temperature, when is required. As an example, if the electric heated windows are working at the same temperature than the rest of the room, 22ºC. Taking into account specialglas electric heated windows characteristics, and considering the power relationship for an outdoor temperature of minus 15ºC, is an equivalent when the electric heated windows works at 120W/m^2. Thus, for a window surface to 57m^2, it gives a power of 6840W and if it guess working for all the productive hours in the office (from 8:00 to 16:00), 8h/day, from monday to friday and during the wintertime, it will suppose that the final energy wasted in the system would be around E=800h*6840W= **5472kWh,** (15% of the total energy more). A result that supposes a 2307kWh more energy needed each year in the case of the installation of the electric heated windows. However, it should be said that this last result is not totally correct, that is a simple estimation one, due to the variation of the outside temperature during all wintertime and the variation of the energy needed for maintaining the 22ºC windows surface temperature, that at the same time is dependent of the variations in the internal gains, as the equipment, lighting or occupant ratings.

In the other hand, as the thermal comfort aspects referred:

Comparing the comfort indices when the whole room temperature increase in one degree and when the electric heated windows are working for 22ºC surface temperature, it is seen that the electric heated option offer some better comfort indices, but however the differences are not so high between them. For the second case simulated, the PPD is similar in both systems, with a PPD of 10% with the first occupant and a PPD of 8% for the other. However, as closer as the occupant is situated, as it could see in the first case simulated, the PPD for the first occupant is to **13%** when increasing one degree the room temperature, and a **PPD of 11%,** when installing the electric heated windows. Also this positive results obtained in the thermal comfort indexes, as it has been said before, the electric heated window offer a possibility to the people working in the offices varies the window temperature when it is required. Therefore, in the case of a cold day in Sandviken, where the outside air temperature could arrive to minus 27ºC in wintertime, this thermal comfort differences could increases exponentially between the two options proposed. While the electric heated windows gives you the opportunity to change instantaneously his surface temperature and thus, change the heat transferred and feel in comfort also when you are near the window, the other option of increase the whole room temperature will suppose a higher amount of energy needed for this case. In this case, maybe the occupant near the window feels in comfort with an increased of the room temperature of around four degrees, but in other hand the occupant working at the bottom of the room is feeling a discomfort at the same time, due to the high temperature there is in the room for his perception.

In these cases, and for a northern country like Sweden, electric heated choice is clearly the better option to use, when we talk about big window surface areas.

DISCUSSION

The process and results section of the project is clearly divided into two different parts, one of them, corresponds for the building previous evaluation before the installation of any electric heated windows and the other shows the results and improvements when the electric heated windows are definitively installed.

In both parts IDA program is used for the obtaining the different results, and later some hand calculations are made to demonstrate the simulation results are correct or not.

About the system analyzed:

First of all, is should be clear that the simulations and calculations shown, corresponds for the first floor of the new building in Sandvik company. Exactly the correspond for the offices area in it, with a dimensions of (18 x 10,78) m. Here, it is considered that all indoor places have an indoor temperature of 22ºC, that means there is not heat transfer thorough the second floor and neither through the different walls, thus, considering only the losses by the windows and the floor of the building. This is estimated, but it is necessary to consider due to the lack of the exact temperature in each size of the wall and roof.

Also is important to say, the data used in the simulation is given to me directly by a study made for another employee in Sweco and the other parameters uses in the project may be not too accurate, but yes similar as the real building construction.

The simulation by IDA program:

The IDA program is a good tool for doing energy calculations. Most of the results obtained in this project are gained with IDA. The exactitude of the data received from the program can vary. There is always a small possibility of defects and difficulties with determining simulations. For instance, one of the automatically consideration of the program, is situated the window with a south orientation and doesn't consider if the weather is cloudy or not, thus having the solar gains are the maximum as possible. For the solution of this problem, the orientations should be chosen as north side and some shadows should be added for the window structure as well. Another input data used for the simulation, as the location of the building is not exact one, in this case Stockholm program database is used for the simulation, while the real results should be calculate for Sandviken, in Gavleborg region.

Finally, as IDA parameters regards, the ventilation system is air handly unit, with a CAV constant air volume, where the correct ventilation rate is used but the program chosen standard system is used for the simulation. The rest of the parameters as for instance the internal heat generation by the occupants, equipment, lighting, are correctly taking into consideration.

How to simulate the electric heated windows work:

In order to simulate the electric heated windows, it couldn't be found a specific menu or direct solution. Thereby, different possibilities for simulation have been tried in this project, some corresponds using the IDA program but even in other kind of program too. Instead of the electric heated window, one of the best possibilities for this could be to use a thin concrete wall with the same U-value as the electric window and given to it the different surface temperatures as the real electric heated windows works. The option of using electric heated windows is not included in the IDA program. This way the results obtained with the simulated electric heated windows are not accurate. Therefore, in this project, the way for simulate the electric heated window is simply to connect an electric radiator under the own windows. Thus, the whole output power for the electric heated window surface is given to the electric heater, trying to transfer the same energy amount for the surroundings. The electric heated windows transfer heat in a homogeneous way for the room, while the radiator transfers too much energy by a small surface, comparing with the windows area. However, regarding the simulation, the program understand the same amount of energy supply, and would offer the same energy balance, thereby it will suppose the thermal comfort indexes are also correct.

Assumption given for the electric heated power imput.

In the other hand, when entering the power of the electric radiators, an important estimation or consideration is taken during this project. Taking into account the specialglas provided electric heated windows characteristics, where the power of the windows varies from 50W/m^2 for a maximum of 400W/m^2, a power of 50 W/m^2 will be used for a surface temperature of 20ºC when the outside temperature is from -15ºC, same as the IDA simulation provides. At the same time, the windows will follow a lineality in the power required, for a final value of 400W/m^2 when the window surface temperature is to 30ºC. Consideration that may be not accurate or correct at all, but necessary to use due to the lack of the exact data given.

Furthermore, the energy needed for the electric heated windows during a period of time, could be very complex to calculate. Besides this, but also the duration of the project, is almost impossible to calculate them and an estimation is given as a final result.

The lack of any electric heated windows working and not having the possibility to check any operation results, it makes the project really difficult to analyze.

CONCLUSION

As the main conclusion for the project, says that this new technology in electric heated windows could be really interesting for research and developed for the near future applications. As I have checked, there are not too much companies working in electric heated windows, and it could be a good opportunity following developing the system. The **advantages** are clear, it uses irradiation instead of the convection of the normal water radiators, it offer really good comfort into the room, it could be varies the temperature in the range of seconds and it only need electricity source to work. No gas, no oil, no hot water pipes are needed, and also avoid the distribution for them. Avoid being dependent of the fuel instable markets and be sure for an inexhaustible supply source as the electricity is. In the other hand, the **disadvantages** are also clear; the energy need for the electric heated is still so big. At the same time as the windows transfer heat indoor, is also transferring heat from outdoor as heat losses. Following Sweco company research, it could be around 30 % of the heat generated, that suppose a big amount of the losses in the system. Therefore, new glass coating, new glass composition or another use of electricity for the generation of the heat should be investigated yet, for the expansion in the markets and to reach for the conventional users.

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APPENDIX

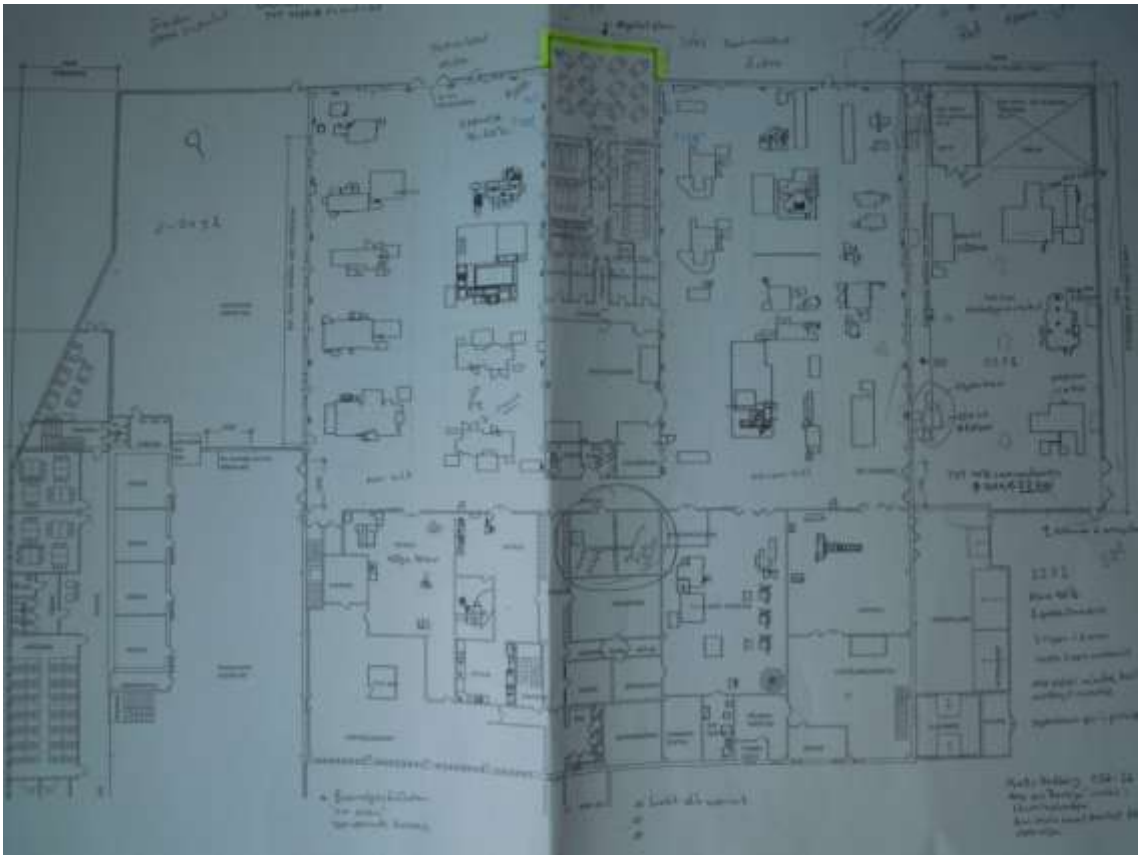
APPENDIX A

Different kind of windows. U-value characteristic:

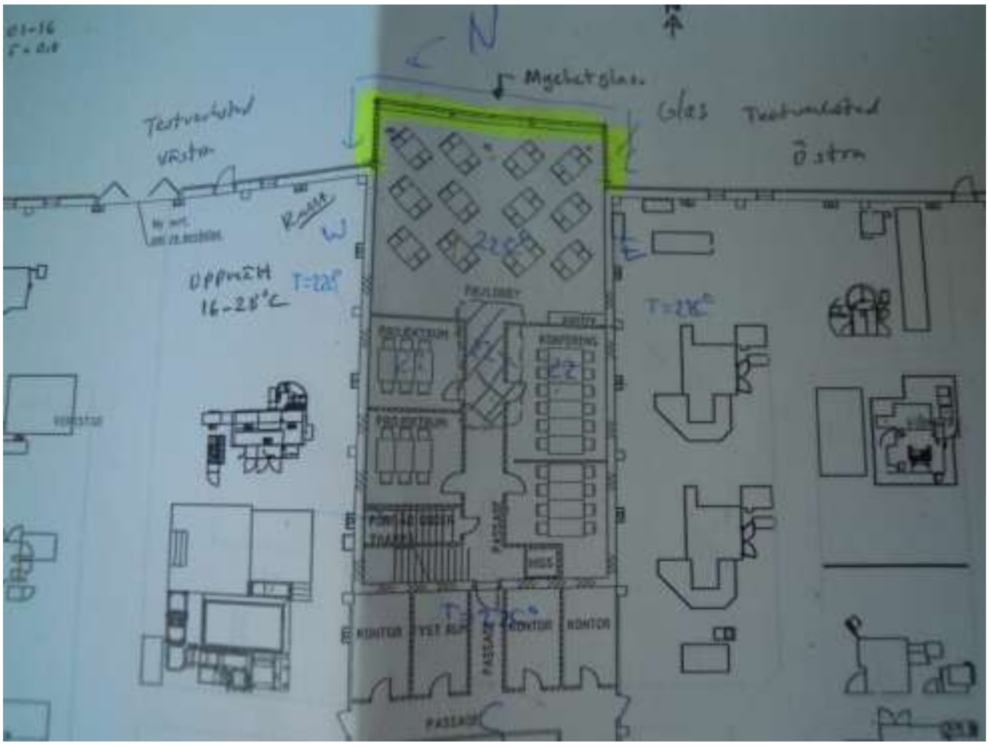
Glazing type	U-value W/m^2K	Solar factor g in %
Double glazing		
12mm air gap no coating on glass	3.0	78
12mm air gap + low e hard coating	1.9	72
12mm air gap + low e soft coating	1.7	58
16mm argon gap + low e hard coating	1.5	72
16mm argon gap + low e soft coating	1.1	58
16mm argon gap + low iron glass + soft coating	1.1	75
Triple glazing		
12mm argon gap + low e hard coating 2 panes	0.9	42
12mm krypton gap + low e soft coating 2 panes	0.6	42

APPENDIX B

-Building planes pictures:



-Working area:



APPENDIX C

Plan 1

	område m2	U-värden W/m2*K	H_T W/K
Golv:			
1m	14,26	0,21479	3,062905
6m	58,71	0,141729	8,32091
< 6m	121,073	0,124135	18,20564
	194,043		**29,58945**

	längd [m]	höjd [m]	område [m^2]		område [m^2]	U-värden [W/m2*K]	H_T [W/K]
Vägg south:							
up till 900 ö.f.g	10,78	0,9	9,702		8,793	0,364	3,200652
mellan 900 - 1200 ö.f.g	10,78	0,3	3,234		2,931	0,339	0,993609
Ovan 2100 ö.f.g	10,78	2,25	24,255		23,3359	0,18	4,200462
Fönster	0	0	0		0	1,2	0
Portar	0	0	0		0	1,5	0
Dörr	1,01	2,11	2,1311		2,1311	1,5	3,19665
			37,191		**37,191**		**11,59137**
Vägg east.							
up till 900 ö.f.g	18	0,9	16,2		15,795	0,364	5,74938
mellan 900 - 1200 ö.f.g	18	0,3	5,4		4,185	0,339	1,418715
Ovan 2100 ö.f.g	18	2,25	40,5		37,2195	0,18	6,69951
Fönster	0,81	1,21	0,9801	5	4,9005	1,2	5,8806
Portar	0	0	0		0	1,5	0
Dörr	0	0	0		0	1,5	0
			62,10		**62,10**		**19,74821**

Vägg west:

up till 900 ö.f.g	18	0,9	16,2		15,795	0,364	5,74938
mellan 900 - 1200 ö.f.g	18	0,3	5,4		4,185	0,339	1,418715
Ovan 2100 ö.f.g	18	2,25	40,5		37,2195	0,18	6,69951
Fönster	0,81	1,21	0,9801	5	4,9005	1,2	5,8806
Portar	0	0	0		0	1,5	0
Dörr	0	0	0		0	1,5	0
			62,10		**62,10**		**19,74821**

Vägg north:

up till 900 ö.f.g	0	0,9	0		0	0,364	0
mellan 900 - 1200 ö.f.g	0	0,3	0		0	0,339	0
Ovan 2100 ö.f.g	0	2,25	0		0	0,18	0
Fönster	16,524	3,45	57,0078		57,0078	1,2	68,40936
Portar	0	0	0		0	1,5	0
Dörr	0	0	0		0	1,5	0
			57,0078		**57,0078**		**68,40936**

APPENDIX D

Calculation for heat losses:

For calculate the building energy calculation the following equation will be used:

Energy = (Kventilation + Ktransmission) * qdegree-hour (eq.13)

1-For the ventilation heat losses, the air flow (*v*) is given us like a data, while *ρ* and *Cp* are knowing values for air.

Kventilation = v * ρ * Cp [W/K] (eq.12)

v (air flow for ventilation)= m^3/s

ρ(air density)=1,2kg/ m^3

Cp(specific heat value) =1000J/kg K

2-For the transmission losses, the U-value of the surfaces in contact with outdoor are required, considering the heat transmission between inner surfaces as zero.

Ktransmission = (U-value*A)roof +(U-value*A)floor + (U-value*A)windows (eq.10)

Finally, to find out *q degree-hour*:

First, the balance temperature should be calculated, that is dependent of the indoor temperature and the internal heat generation in the room.

Tbalance= Tinside – Q(IHG) / (Kv + Ktr) (eq.14)

And a Mean outdoor temperature will be chosen, depending on the location. Where in this case, in Sandviken the mean outdoor temperature is around 5 degrees.

1-Kventilation = v * ρ * Cp [W/K] (eq.12)

Ventilation data:

Monday-Friday: 7:00 to 16:00, (9h a day) 500 l/s→0,5m^3/s

Rest: 100 l/s →0,1m^3/s

In a week, 45h have a ventilation of 0,5m^3/s and the rest 123h has 0.1m^3/s.

An average of: v=$\frac{45*0,5+123*0,1}{168}$ =0,2071$\boldsymbol{m^3/s}$

Thereby,

Kv**=1,2kg/ m^3 ***1000J/kg K * 0,2071$\boldsymbol{m^3}$/s =248,57W/K

2-Ktransmission = (U-value*A)floor + (U-value*A)windows (eq.10)

	U-value (w/m2K)	Area (m2)	U.A
Floor	0,1361	194,04	26,41
Windows	1.5	57.0078	85.5117

(figure 66. Transmission losses table)

Ktr=(26,41+85,5117)=111,92W/K

***3-q degree-hour*:**

Tbalance= Tinside – $\frac{\boldsymbol{Q\ IHG}}{\boldsymbol{Kv+Ktr}}$ (eq.14)

-Tinside=22ºC

-*Q (interal heat generation) data*

Monday-Friday: 8:00 to 16:00, (8h a day) →Devices: 5W/m^2→ 970,2W

Persons: 18 W/m^2→ 3492,72W

Light: 10 W/m^2 → 1940,4W

Rest→1 W/m^2 →194,04W

In total: →→→→→6403,32W

In a week, 50h have 6403,32 and the rest 118h has 194,04W

An average of: Q(ihg)=$\frac{6403,32*50+194,04*118}{168}$ = 2042,04W

Tbalance**=22ºC* – $\frac{2042,04}{(248,57++111.92)}$=16,3353ºC***

Tmean=5ºC

Thereby, checking in degree-hour table: (fig.67).

T_b °C	-2	-1	0	1	2	3	4	5	6	7	8
					T_{mean} °C						
25	238900	229400	220300	211200	202000	192900	184000	17[illegible]900	165600	156800	147300
24	230100	220600	211600	202500	192300	184200	175300	16[illegible]300	157000	148300	138700
23	221400	211900	202900	193800	184600	175600	166700	15[illegible]700	148500	139800	130300
22	212750	203200	194300	185200	176000	167000	158200	14[illegible]200	140000	131300	121900
21	204100	194600	185700	176600	167500	158600	149700	14[illegible]800	131600	123000	113600
20	195500	186100	177200	168100	159000	150100	141300	13[illegible]400	123300	114800	105500
19	187000	177600	168700	159700	150600	141800	133000	12[illegible]200	115200	106700	97600
18	178500	169200	160300	151300	142300	133600	124900	[illegible]	107200	98900	90000
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	108200	99500	91400	82700
16	161700	152500	143800	135000	126100	117500	10900[illegible]	100500	92000	84200	75700
15	153500	144300	135700	127000	118200	109700	101400	93200	84900	77200	69000
14	145400	136300	127700	119200	110500	102300	94100	86100	78000	70600	62700
13	137400	128400	120000	111500	103100	95000	87100	79300	71500	64300	56600

(figure 67. Q degree-hour table [3])

Interpolation:

17ºC---------------------- 108200

16,3353ºC--------------- X

16ºC----------------------100500

X= 108200 –[$\frac{17-16{,}3353}{17-16}$]x (108200-100500) = 103081,81

Finally:

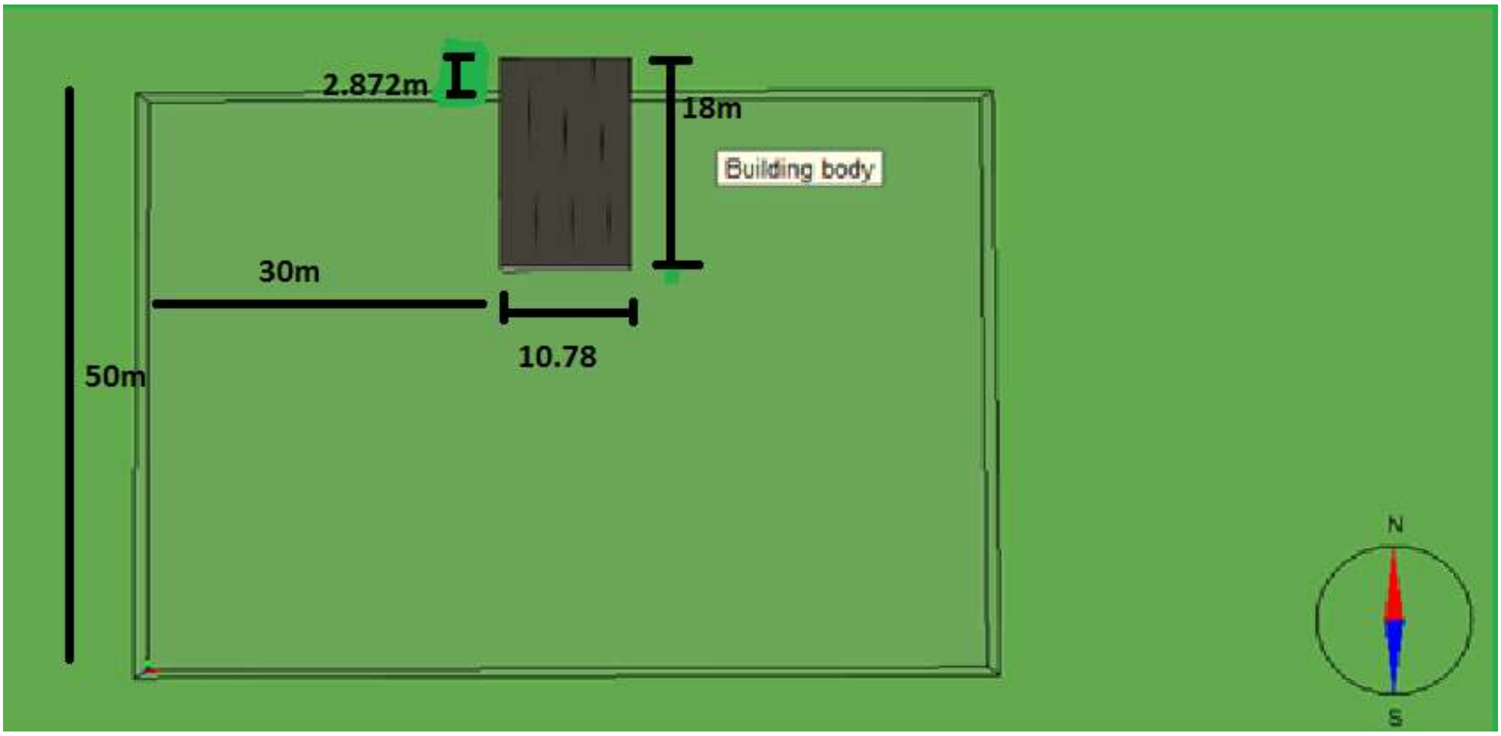
Energy = (Kventilation + Ktransmission) * qdegree-hour (eq. 13)

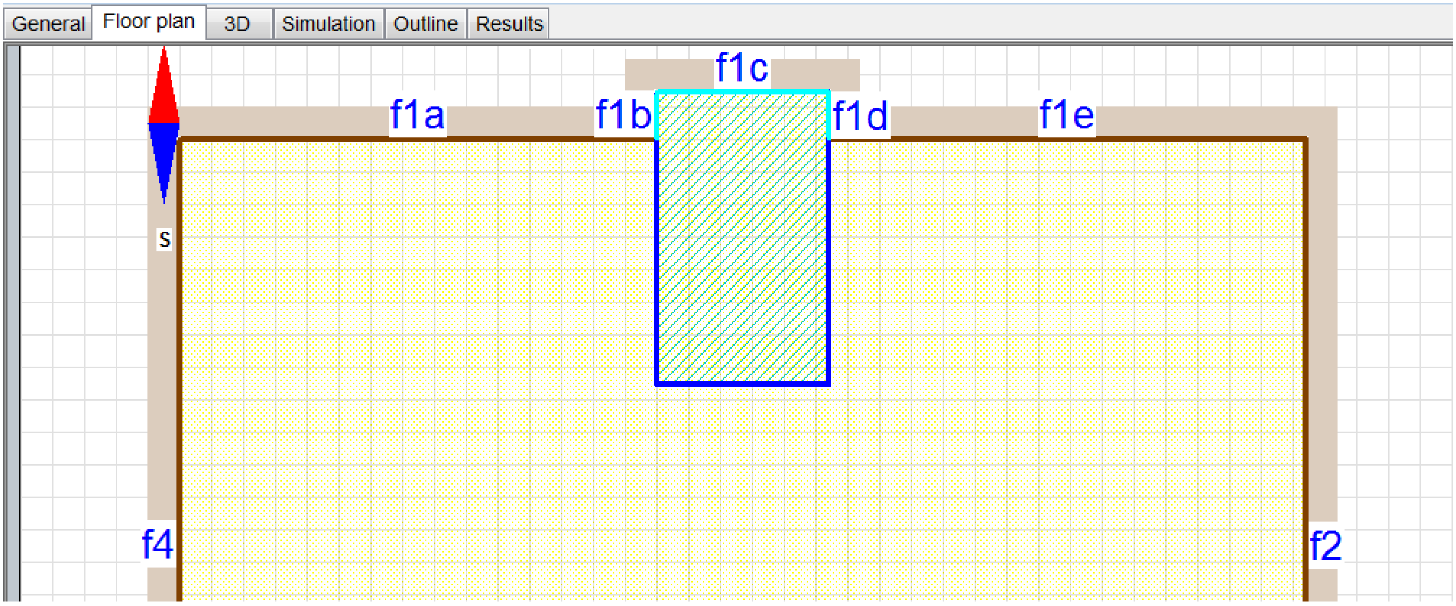
E=(248,57+111,92)*103081,81= 37,16MWh

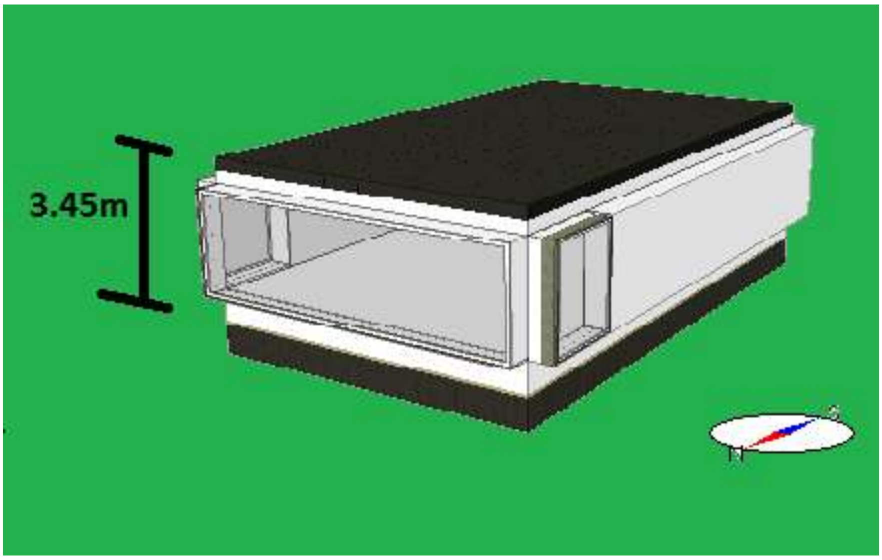
APPENDIX E

IDA program simulation

-Defined the building body and the working zone:







Input data used in the program:

-Location and weather:

Global Data

Location: © Stockholm/Bromma

Climate: © Synthetic (winter)

Wind profile: © [Default urban]

Location: © Stockholm/Bromma

Position

Country	Sweden			
City	Stockholm, Bromma			
Latitude	59.35 N °	Elevation	11	m
Longitude	17.95 E °	Time zone	1 E	h

Design days

	Winter	Summer	
Dry-bulb min	-18.3	17.3	°C
Dry-bulb max	-13.9	26.1	°C
Wet-bulb max	-14.1	17.1	°C
Wind direction	320	200	°
Wind speed	1.8	3.9	m/s
Clearness number	1.0	1.0	0-1

Climate description: <value not set>

Object

Name: Stockholm/Bromma

Description: Data from ASHRAE Fundamentals 2001

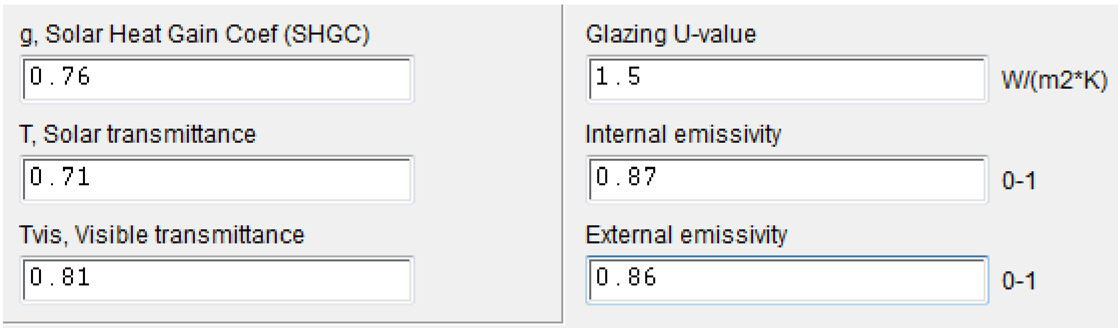
-Materials and U-values:

-U-value in walls, and also in the roof for the first window doesn't matter. There are not heat transfer through. U-value= $3.10^{-16} \approx 0$.

-U-value **floor** =0,1361 W/m2 ° C [d=1m, λ=0,138, density= 1 kg/m3 , specific heat = 1Kj/(kg K)]

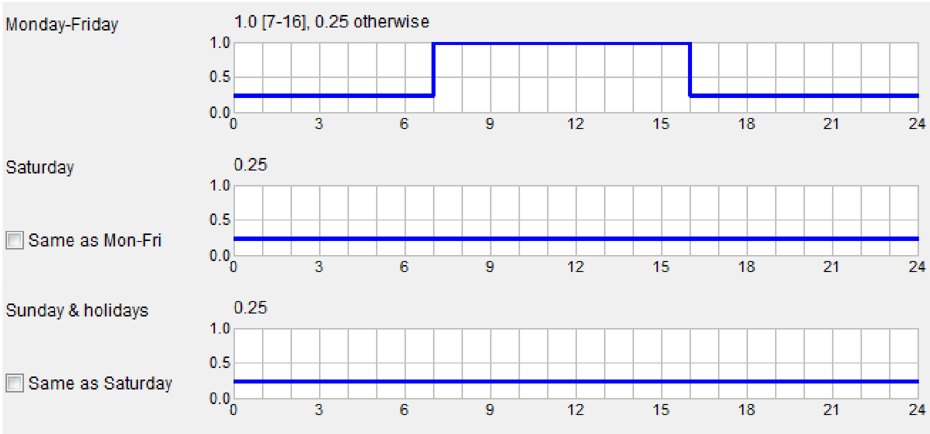
-Windows: 6mm-16mm-6mm

U-value =1.5 W/m^2K

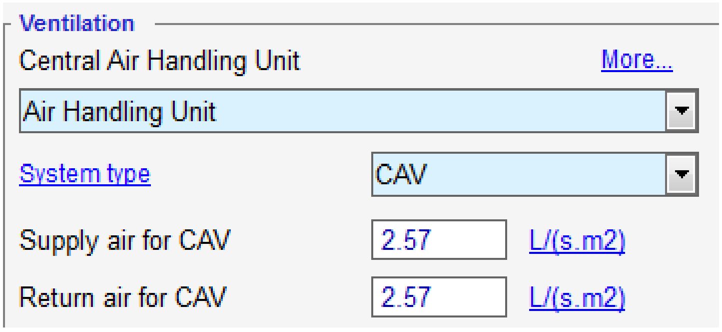


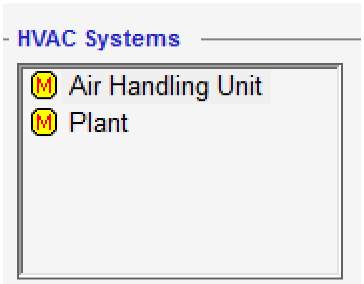
-Ventilation system:

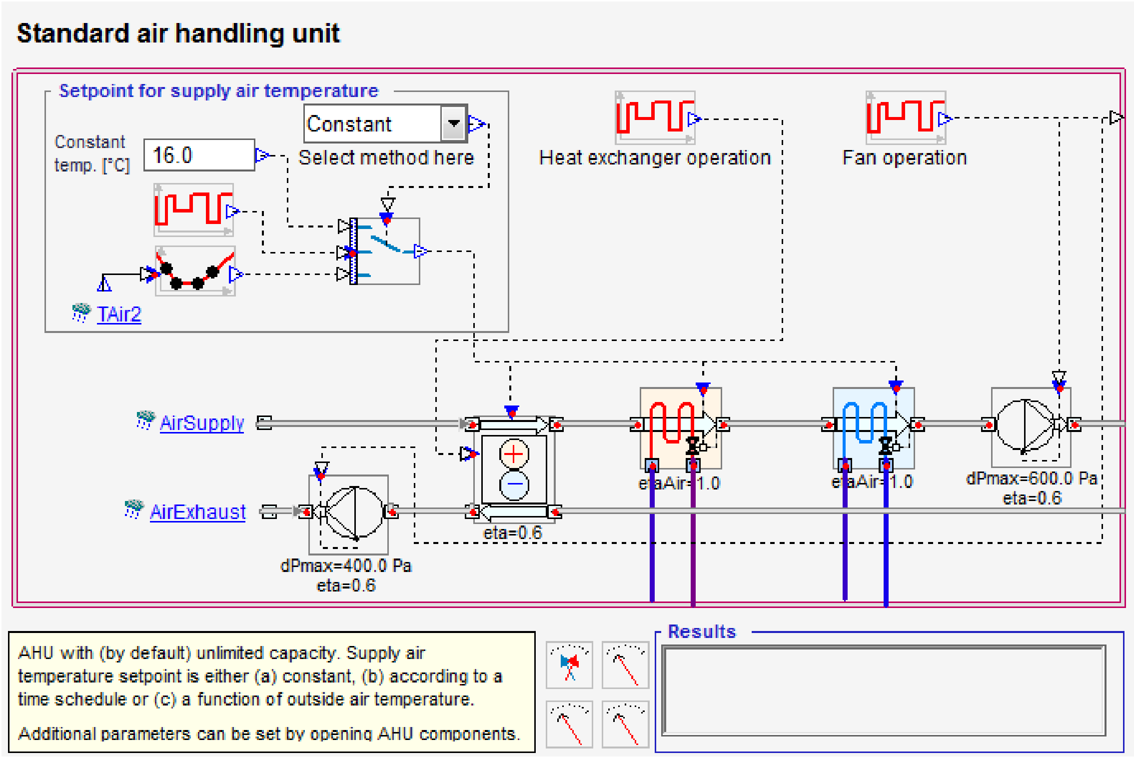
	Monday-Friday: 7:00 to 16:00	Rest of the time, also weekends
Floor 1	500 l/s	100 l/s



Having a S=194m^2, means a ventilation of around 2.57l/s.m^2







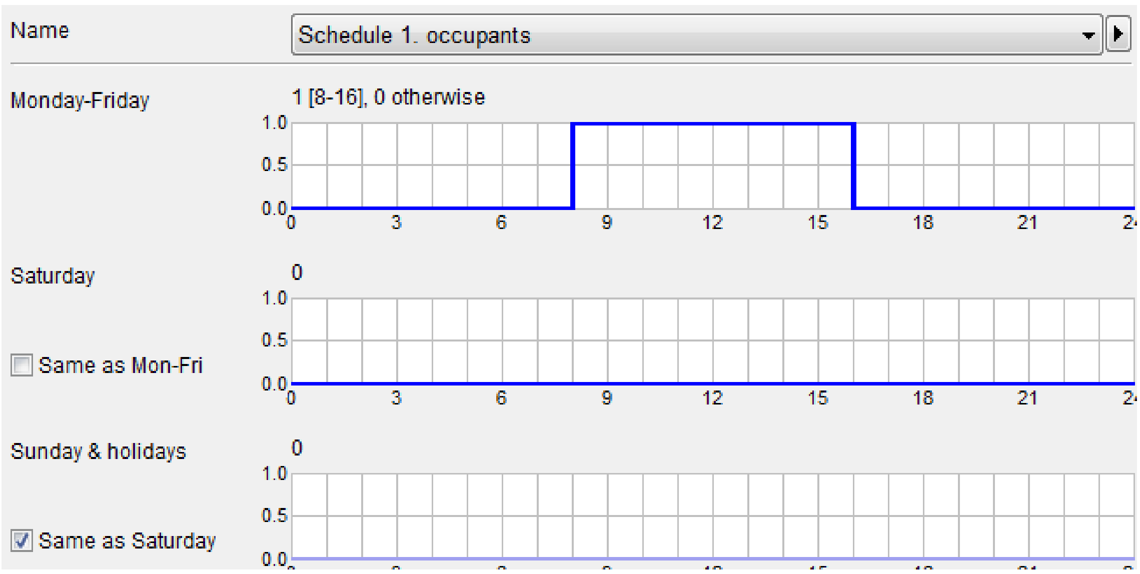
-Internal load:

Monday-Friday, 8:00 to 16:00 → Devices: 5W/m^2

Persons: 18 W/m^2

Ligth: 10 W/m^2

Rest→1 W/m^2



-Finally, the control set points are introduced as the following: